Monhegan Museum of Art & History

White Paper

Grant #: PF-230283-15

Creating a Sustainable Preservation Environment

Project Director: Jennifer Pye
Monhegan Historical & Cultural Museum Association
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Background

The Monhegan Museum of Art & History is housed in the 1824 Monhegan Island Light Station located atop a small island, 11 miles off the coast of Maine. Our dramatic location creates one of the largest draws to the island for residents, tourists, and artists alike- however it also presents a number of challenges. These include: extreme wind, high humidity for much of the year, lack of access to maintenance technicians, electrical costs of well over 5 times the rate on the mainland, and an infrequent and often rough crossing on the island's mail boat.

In 2006, the Monhegan Museum of Art & History participated in the Collections Assessment for Preservation Program. John Leeke- an expert in the preservation of historic structures, and Ron Harvey- an objects conservator spent several days on-site evaluating the condition of the buildings and the collections environment. Their resulting reports provided necessary guidance for the subsequent steps toward improving the longevity of our collections and historic buildings.

Based on the recommendations of Leeke and Harvey, The museum applied for and received an NEH Preservation Assistance Grant in 2010 in order to purchase 10 PEM2s; and for Jeremy Linden of the Image Permanence Institute to provide staff training in the use of the monitors and in eClimateNotebook to interpret the data being collected. A few years of data collection led to a better understanding of the conditions that the collections were subjected to throughout the year, and the inherent risks associated. In 2013 the museum was awarded a Sustaining Cultural Heritage Collections planning grant to work with Leeke, Harvey, Linden, and ICDS[1] to develop a strategy to improve conditions at the museum through both passive and mechanical ways- remaining mindful of the historic nature of the Monhegan Light Station and the significant expense of both propane gas and electricity. The Monhegan Museum Plan for a Sustainable Preservation Environment was completed in February of 2015, and with few deviations formed the roadmap for this implementation project.

Project Activities

The Monhegan Museum received $250,000 in grant funding from the NEH SCHC grant with an additional $50,000 in matching funds toward a $496,080 sustainability project. The implementation team consisted entirely of members who were already familiar with the site, the conditions, and the island. John Leeke, Ron Harvey, Jeremy Linden, and ICDS worked with museum staff, as well as with our caretaker- Victor Lord, and Chris Smith of the Monhegan Plantation Power District (MPPD) to assess progress, interpret data, adjust mechanical settings, and modify plans as necessary.

A significant piece of this project is based on a partnership with MPPD. Due to the distance of the island from the mainland, electricity is generated on-island rather than provided by a cable from the mainland. In an effort to reduce emissions and fuel consumption, the Monhegan Plantation Power District replaced their diesel generators with energy efficient micro-turbines in 2016. MPPD is located on Lighthouse Hill, near the museum, and these air-cooled micro-turbines create a tremendous amount of heat. Recovering this heat and using it for other purposes greatly increases the efficiency of the machines. Heat recovery from these turbines was employed to reduce the Museum's dependence on electricity and propane to control climate in collections spaces.

As this was a complex project that involved several distinct structures and a mixture of passive and mechanical approaches it is simplest to describe the steps taken with each building individually.

[1] Innovative Construction and Design Solutions (ICDS) is an engineering firm composed of Scott Fitch and Dan Fisher. They designed the initial mechanical system for the Main Vault installed in 1998 and worked with MPPD to facilitate the transition from diesel generators to micro-turbines.

The Light Keeper's House- Built in 1824 and modified several times with all major additions completed by 1892. This structure is listed in the National Register of Historic Places. This building is used to house exhibits about island art, history, and natural history. The most delicate items such as artwork and photographs are removed in the winter and placed in climate-controlled storage. The objective for this structure was to improve conditions as much as possible without the addition of mechanical controls which would change the nature of the historic building. Most of this building relies on natural light for illumination. Numerous passive approaches were employed to reduce moisture and light levels and to reduce temperature fluctuations. These included:

- *Address fissures in foundation.* All water from the downspouts had been routed away from the building during the implementation portion of the planning grant; however cracks and obsolete inlets into the foundation continued to allow water infiltration. These cracks were filled with mortar in keeping with what was used in the original foundation.
- *Replace water tank in basement*. The open water tank in the basement was replaced with a sealed tank to reduce evaporation and the resulting condensation on the joists and underside of the first floor.
- *Replace and relocate electric panel.* The electric panel, though only ten years old, was extremely corroded due to being installed in a damp corner of the basement. The panel was replaced and installed at the top of the basement stairs for greater ease of access and to move it away from the highest RH conditions.
- *Fill holes in flooring.* In order to reduce moisture levels coming from the below-ground basement, wooden plugs were fitted into holes on the first floor that were left over from the piping used to feed iron radiators.
- *Refurbish Windows.* It was not possible to open a large number of windows in the Keeper's House. The budget included refurbishing seven windows to allow them to open and close easily for ventilation. When work began, it became clear that many of the windows could benefit from more extensive restoration. A $10,000 grant from the Morton Kelly Foundation allowed for a more thorough and detailed approach to this portion of the project- combining the preservation of the historic windows with the increased functionality.
- *Storm Windows.* The original plan called for historically appropriate mahogany storm windows fitted with UV glass to be fabricated and installed on the South and West facing sides of the building to reduce solar gain and diminish UV damage to artifacts. This plan was modified during the first meeting with the consultants in 2016. The storm windows were fabricated and installed on the South and West sides, but included regular glass rather than UV. Instead of shielding two sides of the building from UV light, the decision was made to cut UV-filtering Plexiglas panels to be pinned in place over each pane of glass in the display areas.
- *Insulating window panels.* Windows on the North and East facing walls were fitted with polyisocyanurate panels to prevent heat loss and regulate temperature fluctuations during the winter months. Storm windows on the South and West facing walls allow for solar gain.
- *Window Shades.* A light filtering shade and a light blocking shade was installed on each window throughout the building. The initial plan called for dual roller shades, but these proved too cumbersome and the depth of the shade was a distraction in the exhibit spaces. Instead, an interior mount light filtering shade and an exterior mount light blocking shade was installed in each window.
- *Use the existing two chimneys for ventilation*. The plan to install operational vents in the chimneys to release moist air from the buildings was put on hold by the project team. All participants felt that more data was needed from the measures already taken before pursuing these vents as there are no existing case studies about their efficacy.
- ***Introduce low level of heat to basement in winter months.*** Not part of the initial plan, and separately funded- while the heating loop was being installed to the climate controlled buildings a leg was added to

raise the temperature slightly in the Keeper's House basement during the winter months. A simple fin tube radiator in the basement was set to 45 degrees to drive moisture from the building, prevent dramatically low temperatures, and as a side effect, raise the temperature in the Keeper's house to an above-freezing level so that a fire alarm that can send a wireless broadcast in case of emergency can be installed.

The Assistant Keeper's House- The 1998 reconstruction of the Assistant Keeper's House that was torn down in 1928 holds an art gallery and the office/archives.

The Gallery- this large open space with cathedral ceilings is used seasonally for art display, including loaned materials from other institutions. The largest concern in this space was the high humidity levels.

- *Moisture barrier.* A layer of 6mil plastic was laid over the exposed earth beneath the gallery to prevent moisture from the soil from causing condensation beneath the gallery.
- *Spray foam insulation.* A one inch layer of closed cell spray foam insulation was applied to the underside of the floor to provide insulation as well as a vapor barrier.
- *Lighting.* In the original plan the lighting in the gallery was to be replaced with LED fixtures. This portion of the project was postponed due to the monetary amount granted being less than what was requested in order to pursue all of the goals of the project.

The Gallery and Office/Archives-

- *Mechanical dehumidification.* NovelAire ComfortDry 250 desiccant dehumidifiers were installed. Solar collectors on the office/archives roof work to provide the hot water to dry the desiccant. When conditions are not optimal for the solar collectors, reclaimed heat from MPPD is used to heat the water/glycol mix that provides the heat to dry the desiccant.
- *Heat.* Solar collectors are used to provide heat to these spaces when supply is sufficient. The primary backup is heat reclaimed from MPPD, if the micro-turbines equipped with heat recovery are off-line an energy efficient propane boiler provides an emergency source of heat.

The Main Vault- This 1998 well-insulated cinder block construction was built as a climate controlled storage space for art collections. The solar collectors and heat recovery mentioned previously have also been employed in the vault as a sustainable alternative to the aging and expensive electric heat and dehumidification system previously installed.

The Ice House Vault- This structure that once served as a garage for the Light Station had been used to house the Ice Cutting exhibit on the first floor[2], and the second floor attic space was renovated to be used as climate controlled storage in 2005. Due to growing collections it was necessary to convert the first floor of this space to additional climate controlled storage. The original mechanical equipment for this space had been troublesome since installation and was rarely fully functional. It has been replaced and this structure is also now served by the previously mentioned heat loop. In the original plan the outer sheathing of the building was to be removed, a layer of reflective foam insulation and a vapor barrier applied, and the cedar shakes reapplied. Upon reviewing this plan on-site with the consultants and the caretaker, followed by consultation with the Maine Historic Preservation Commission, the plan was adjusted to installing 3 inches of polyisocyanurate foam insulation between the wall joists. The insulation was sealed to the wall joists with aluminum tape to create a vapor barrier. The floorboards were removed and soil beneath the building graded and a 6mil plastic vapor barrier put in place. Six inches of

[2] An addition to the museum's workshop has been completed to house the Ice Cutting exhibit with assistance from the Davis Family Foundation. The exhibit will be reinstalled for summer 2019.

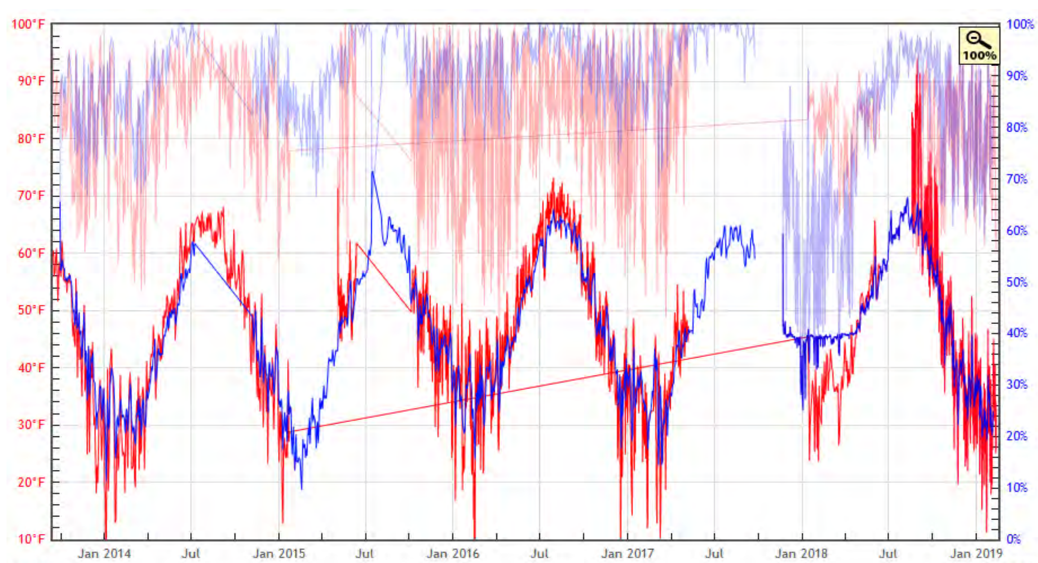
polyisocyanurate foam was installed beneath the new floor which was then covered with Armstrong Bioflooring. The walls were sheathed in fire-retardant sheet rock, and powder coated metal shelving and art hanging screens were installed. 3000K tube style LED fixtures were wired for illumination, and the window was replaced with a custom-built non-opening unit. The window has an 80% gray painted sheet of plywood and insulation behind it and is covered with sheetrock on the inside, but preserves the original fenestration of the exterior of the building. An energy-efficient frost-free upright freezer was also installed in this space or the storage of color slides and photographs.

The Rockwell Kent/James Fitzgerald Legacy- The initial grant proposal included addressing a number of concerns at a separate campus of the museum- the house and studio built by Rockwell Kent in the early 20th century, and later owned and used by the artist James Fitzgerald. It was necessary to trim the project due to the fact that less funding was available than had been requested. As the Kent/Fitzgerald Legacy is physically separate from the museum, this piece was removed from the current project and will be revisited in the future.

Accomplishments

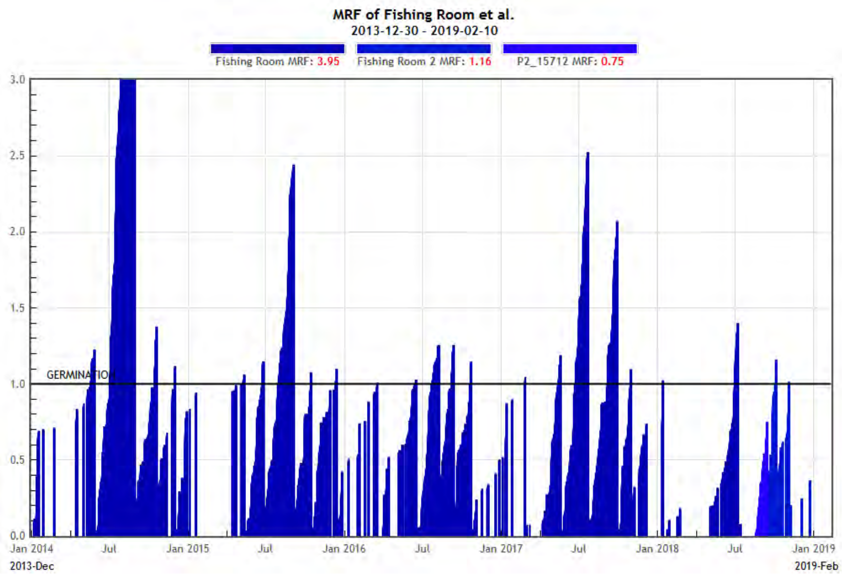
Keeper's House. In the historic Keeper's House numerous passive measures were undertaken to improve environmental conditions. The first area addressed was the basement where the relative humidity (RH) was frequently measured at 100%. The following graph shows the change in temperature and humidity over the years. The dark red line represents the outside ambient temperature, the pale red - the outside RH, the dark blue represents the basement temperature, and the pale blue the RH. Sealing the basement, and removing the standing water has resulted in a lower RH year-round in both the basement and the first floor, and the changes in temperature and RH are less extreme than the outside ambient fluctuations. When the building was opened in the spring of 2018 there was no visible mold growth in the spaces where it has come to be expected due to its annual occurrence.

During the winter of 2017-2018 the addition of heat to the basement kept the temperature at a minimum of 45 degrees and significantly reduced the RH in the space. It is our intention to continue to heat this space; however the underground tubing that supplies the heated water/glycol to this building was punctured during the installation of a tent for the celebration of the museum's 50th anniversary during the summer of 2018. Parts to repair the puncture are on hand, but the necessary tool is backordered. We anticipate that the pipe will be repaired before the end of March 2019.

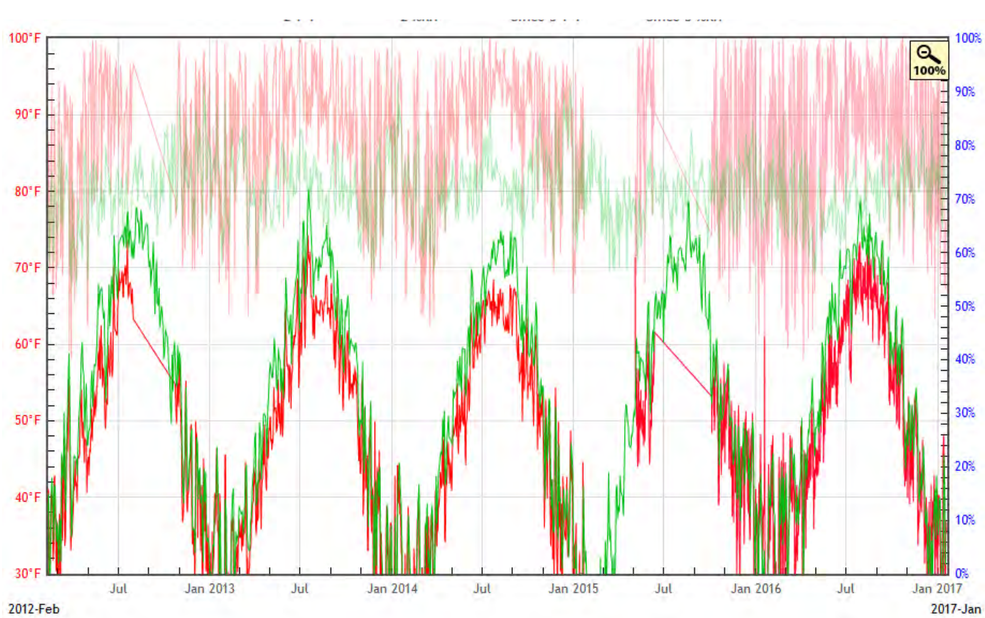


The summer of 2018 brought unprecedented heat as can be seen by the red line on the graph. This makes it difficult to draw conclusions about the ultimate success of the project without further data. Environmental monitors remain in place, and conditions will continue to be observed.

Improvements to the conditions in the basement translate into lower RH on the upper floors. This graph shows how the potential for mold growth in the Fishing Room display space on the first floor has continuously diminished.



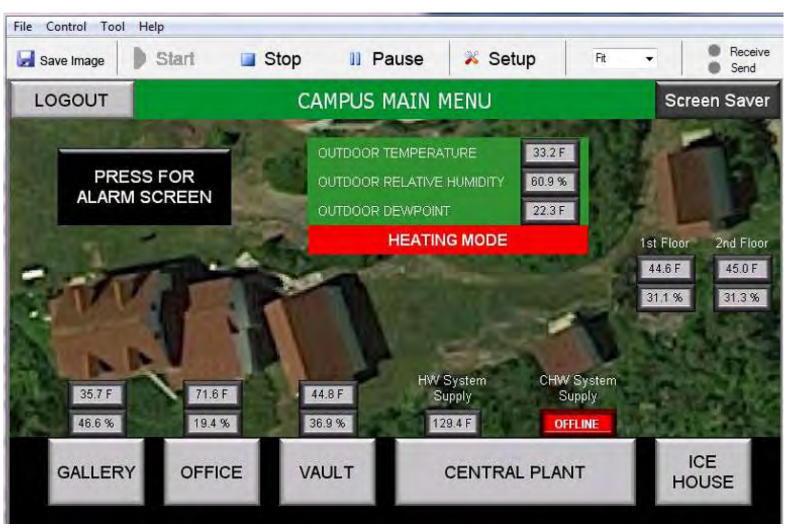
The following graph shows the temperature and relative humidity on the second floor of the Keeper's House (green) compared to the exterior conditions (red). Window work completed during the spring of 2017 allowed for windows on the second floor to be opened for ventilation. This resulted in the interior temperature more closely mirroring that of the exterior- rather than being several degrees higher. This also shows a modest decrease in RH.



Steps taken to reduce moisture in the basement, lessen temperature fluctuations in the winter, and increase summertime ventilation do not have immediate and dramatic results, but early data indicates that several critical risk factors - condensation and mold in the basement, mold on the first floor, and exceedingly high RH conditions throughout the building, may have been positively impacted. Weather variations from year-to-year make it impossible to develop a clear picture of how successful modifications have been with less than 2 years of data. Environmental monitoring indicates that there have been positive changes in the climate of the Keeper's House, and we will continue to collect and review data. Several of the aging PEMs failed during the project which resulted in a loss of data while it was determined if they could be repaired.

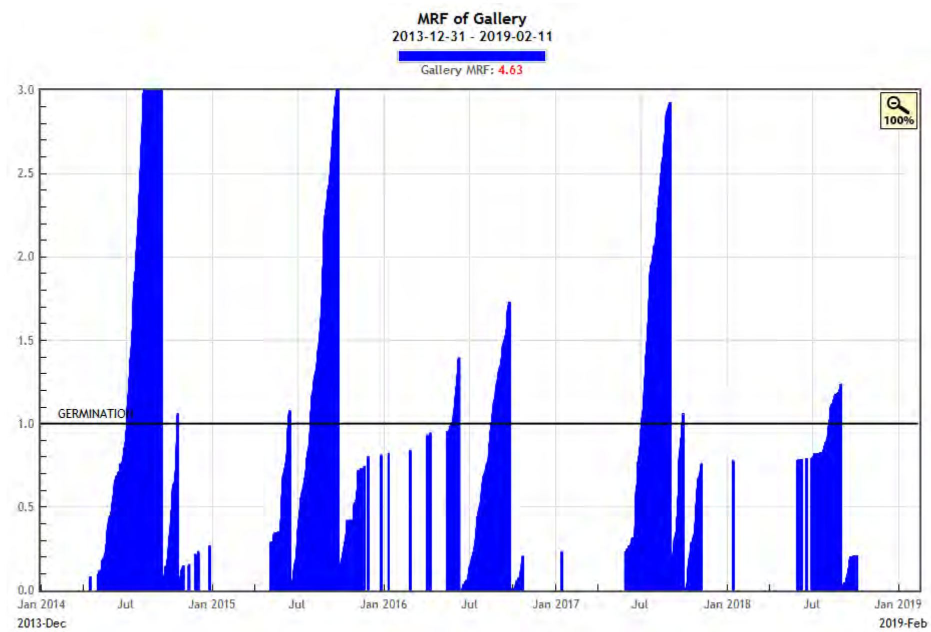
Of the many approaches taken to improve environmental conditions throughout the museum, the simplest and most clearly effective was the window treatments undertaken to reduce light and UV levels. In 2016, before the UV Plexiglas panels were fitted over each window pane, UV levels were measured as high as 569 microwatts per lumen, and light levels reached as high as 1471 lux. These measurements were taken at the surface of paintings. Generally accepted recommendations for light levels are 50-150 lumens for artwork and UV levels as low as possible, but not over 75 microwatts per lumen. Measurements taken on a sunny afternoon after the installation of UV Plexiglas and light filtering and light blocking shades showed light levels averaging at 146 lux and with most UV readings at 0, and none above 52 microwatts per lumen. Light blocking shades are completely drawn other than for the four hours per day that the museum is open in the summer months to further reduce potential light damage, light readings continue to be taken throughout the season to determine the optimal height to raise the shades with consideration given to atmospheric conditions, and comfort of the viewer. There is little electric lighting in the Keeper's House and illumination is mainly from light coming through the windows. This results in some areas having light levels that are not ideal for artwork display in order to make sure that other parts of the room are adequately illuminated. Going forward, less sensitive items and archival copies of photographs will be displayed in areas where light levels are higher than recommended; and the museum will continue the practice of rotating the art collections on display in the interest of preservation. As a rule, each artwork is displayed for no more than four months of every three years.

Mechanical Controls. The combination of solar collectors, reclaimed heat from MPPD, a propane boiler for back-up heat, and chillers allow the museum to achieve greatly improved conditions for collections. The amount of space that can be climate controlled is four times greater than was available prior to this project. Near-optimal conditions are possible in all of these spaces. Determining the appropriate balance between preservation and energy consumption is an ongoing process. Remote access to environmental controls allows museum staff to view current conditions and alter set points from a smartphone or computer. This allows for experimentation with night time shut downs and other energy saving measures.



The Office/Archives and Gallery- The office was previously heated with propane monitor heaters during the winter months, and the gallery had no environmental controls. Heat is now provided to both of these spaces through air vents in the floor, alleviating concerns of fire due to items left too close to a propane heater. The gallery space is used for photography of collections during the winter months; while the space is not regularly heated, having the option of heating the space greatly increases staff comfort and the number of days that photography is possible.

The RH of the Gallery during the summer of 2018 was reduced to an average of about 65% from the past level of an average of 80%, and the mold risk factor was significantly lessened. We anticipate that the risk will be eliminated in the future as the small risk indicated in 2018 was as a result of equipment failure at MPPD.



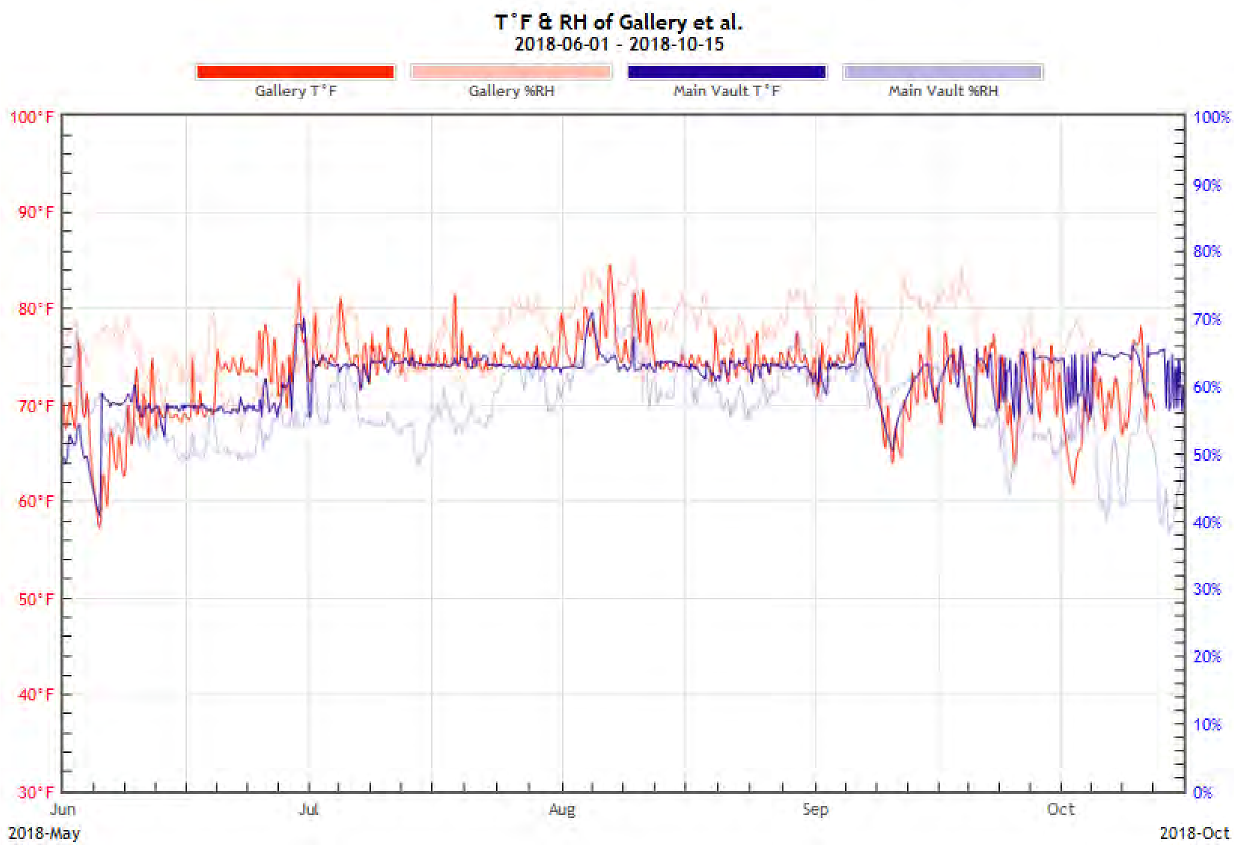
The Main Vault- The only major change in this space is the source of the heating, cooling, and dehumidification. Set points continue to be adjusted to reduce energy use. Winter temperature has currently been set back to 45 degrees in order to increase RH during the dry cold months. Mechanical humidification is not an option because the island water supply is above-ground and is drained to prevent freezing in the winter.

The Ice House Vault- This space has been successfully converted from an uninsulated shed to a well-insulated climate controlled space. All equipment and settings are the same as those in the Main Vault. Artwork screens provide over 1500 square feet of storage space, color slides and photographs have been packaged according to National Park Service guidelines and are housed in the frost-free freezer, and sensitive archival materials are being transferred to the shelving in this space.

Numerous issues delayed the installation of the climate control equipment and heat loop. These included damages to equipment during shipping, contractor delays, obtaining permits, and difficulty finding an electrical and heating contractor willing to come to Monhegan. Ultimately, it was necessary to hire separate companies for electrical and plumbing, ductwork, and duct insulation. This caused further delays as each company relied on the others to meet a schedule, and if one piece was delayed, all involved needed to delay their work. The initially scheduled date for commissioning the heat loop was November 2016; the system was commissioned in November of 2017, with the chillers coming online in June of 2018. Throughout the winter of 2017 the heat loop worked very well. And even on the coldest days the solar thermal system could handle the load for part of the day if the sun was shining.

During the summer of 2018 MDDP faced ongoing mechanical failures with the micro-turbines. These appear to be a result of the systems having been refitted to be fueled by diesel rather than natural gas, and the micro-turbine manufacturer is working with MPPD to solve the issues- however for the summer of 2018 this caused MPPD to have to engage the back-up diesel generator. This aging machine is meant only for emergency use and barely has the capacity to supply the island during the high demand summer months. In order to keep the struggling machine from being overwhelmed by the demand, MPPD requested that the Monhegan Museum forego the use of our chillers until the micro-turbines were functioning. 2018 was one of the hottest summers ever recorded on Monhegan and the desiccant dehumidifiers added further heat to the gallery and vaults. It became necessary to shut down the mechanical controls completely for an extended period of time to allow the temperature to drop in collections spaces. Additionally, the puncture in the heating loop leg to the Keeper's House also caused a multi-day system shut-down until that leg could be isolated. All of these events make it difficult to ascertain how successful this portion of the project has been without further data collection.

The following graph shows the temperature and RH of both the Gallery and the purpose- built Main Vault over the summer of 2018. Temperature and humidity were a significant concern in the heavily visited gallery, but the Main Vault maintained temperature and RH well despite the shutdowns, which bodes well for more extensive experimentation with operation for energy-reduction in the future..



Attached reports (Appendix A) compare conditions in the gallery during the 2017 season (unconditioned) and the 2018 season (partially conditioned). The TWPI (time weighted preservation index) for 2018 is actually slightly lower than that in 2017- meaning that rates of chemical decay were slightly worse due to consistently warmer temperatures (primarily due to outdoor conditions and lack of cooling), but the mold risk was greatly diminished. With the environmental controls only partially working for one season, the data available is insufficient to accurately measure the success of the project.

The power usage since 2012 (Appendix B) indicates that while consumption went up significantly when the chillers were employed, it is still not significantly higher for the year 2018 than it was in the year 2012 which was likely the last year that all of the mechanical equipment for the previous two vault spaces was fully functional. Propane, previously used to heat the office/archives was an annual expense of over $2300 (16+ 100lb. tanks), is now only used to fire the boiler in the event that the micro-turbines are offline. Midway through February of 2019, the boiler has been used for less than 24 hours for the 2018-2019 winter and has burned less than one tank of propane.

All project activities were completed within the grant period, however there has not been sufficient time to monitor results in order to fully determine what conditions we are able to achieve- and at what cost.

Audiences

The multifaceted approach to the collections environment at the Monhegan Museum in combination with the variety of modern and historic structures can provide useful information about working with community partners, and both passive and mechanical approaches to preservation for many small museums and historic houses attempting to improve conditions for their collections. It is difficult to determine a specific on-site audience for this project, though the results will mean a greater longevity for the collections which are seen by over 6000 visitors per year.

Community support was evident in the rapid response to our request for $50,000 in matching funds at the outset of the project. The full amount was donated in less than one month.

Jeremy Linden has spoken about this project at various conferences including AIC 2016 with Ron Harvey and Jennifer Pye. Jennifer Pye was invited to address the crowd gathered at the ribbon cutting for MPPD in celebration of the new generation system at the power plant and of the partnership between the utility and the museum. A chapter in the 172 page hard bound book-*The Monhegan Museum: Celebrating 50 Years* was dedicated to the sustainability improvements at the museum. The 2017 Island Energy Conference offered a site visit to Monhegan where they were given a tour of the Power Plant and the museum. Articles about this project appeared in *The Working Waterfront, Maine Archives and Museums Newsletter*, the Monhegan Museum e-newsletter, and on the NEH website. Jeremy Linden, Ron Harvey, Scott Fitch of ICDS, and Jennifer Pye will present project findings and results at the 2019 AIC Conference.

Evaluation

The project was evaluated at each annual meeting of participants, and modifications were made as necessary. A written evaluation by Jeremy Linden is attached (Appendix C). An in-house evaluation based on the experience of the museum staff follows.

In retrospect, this was an extremely ambitious project to undertake with a part-time staff of four, but we relied heavily on the support, experience, and expertise of the consultants who also helped draft the implementation plan and had been involved with the museum for many years. MPPD Plant Manager, Chris Smith was not listed as a participant in the application, but his assistance has been essential. Working with ICDS to install the micro-turbines at MPPD and to the mechanical systems at the museum he is familiar with all aspects of the equipment and able to troubleshoot issues on-site in consultation with ICDS.

An aspect that was not thoroughly considered in the application process was the involvement of the Maine Historic Preservation Commission. Consultation with MHPC earlier in the process would have been valuable for exploring options about how best to repurpose the Garage/Ice Cutting building as a vault. Additionally, consultation with the Monhegan Plantation officials, and the Monhegan Associates (abutting land owners) prior to the grant award would have allowed the trenching and laying of pipe from MPPD to the museum to proceed more swiftly. As both of these entities are managed by a board, it was necessary for them to arrange meetings and discuss the potential impacts before signing an easement or presenting their requirements for installing piping across their property.

The community, the Plantation, and the Monhegan Associates were all enthusiastic and supportive of this project and the partnership between the museum and MPPD. The Island Institute used the project as an example of energy efficiency and community partnership.

Expenses relating to the renovation of the Ice House/Garage to a climate-controlled storage space ran over budget as did the cost of laying an underground pipe to MPPD. Expenses related to lodging were alleviated by housing consultants in buildings owned by the museum. The final cost of the project came in at just over 5% over budget.

Continuation of the Project

As mentioned previously, environmental data will continue to be collected and set points adjusted for efficiency. Currently the goal is to pursue funding for three additional years in order to continue consulting with Linden Preservation Services, Ron Harvey, and ICDS to monitor conditions, experiment with nighttime shut downs and general set points, and ultimately present our findings in a public forum. Additionally, funding will be sought to hire an energy expert to work with MPPD and Monhegan Museum to negotiate a purchase agreement for the waste heat used by the museum. Currently, the project is considered to be in “test mode” and fees will not be charged until the supply is reliable.

Long Term Impact

The primary predicted long term impact of this project is increased longevity for Monhegan Museum collections at little or no increase in energy cost. This enhances the sustainability of the museum, and by receiving payment for their waste heat- MPPD as well.

Piping Images from MPPD to Museum

3 foot deep trench from MPPD to the museum for heat recovery piping.

Distance of MPPD from Museum. Trench runs in a reverse C-shape along the edge of the road.

Ice House Renovation Images

1. Ice Cutting exhibit prior to modification of the space.

2. After floor removal, soil was remove from beneath building to create space for ductwork.

3. Floor joists were reinforced.

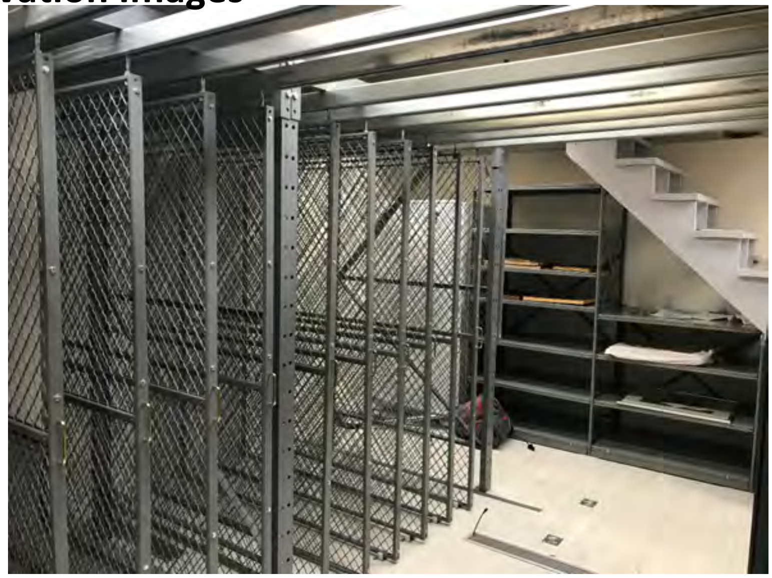
4. Multiple layers of polyisocyanurate insulation were applied between wall joists.

5. Aluminum tape between insulation boards forms a vapor barrier

6. Insulated duct work beneath floor.

Ice House Renovation Images

7. Two layers of subfloor, flooring, and sheetrock installed.



8. Artwork screens, shelving, and freezer installed.

9. Collections housed in new space.

10. Window replaced with a non-opening window for better weather protection. Dark gray plywood and insulation on interior of window.

11. Climate control equipment installation in vault mechanical room.

Solar Collectiors on Office/Archives Roof

Window Images

Window test fit.

Storm windows installed

Plexiglas panes held in place by small pins. Air space between the Plexiglas and the glass is created by cutting Bumpons into quarters and sticking them to the edges of the Plexiglas.

5% open weave light filtering shade is mounted to the interior of the window frame. Light blocking shade mounted to the exterior.

Gallery

Monhegan Museum • Assistant Keeper's House • 1st Floor • Gallery
Monhegan Museum

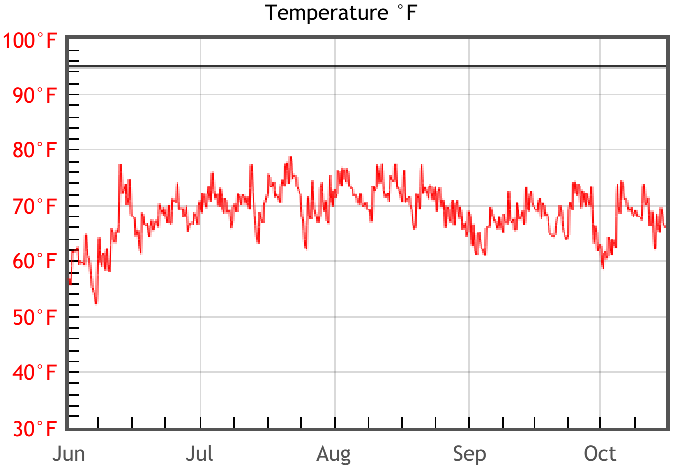
2017-06-01 to 2017-10-15
4 months, 15 days

Preservation Environment Evaluation

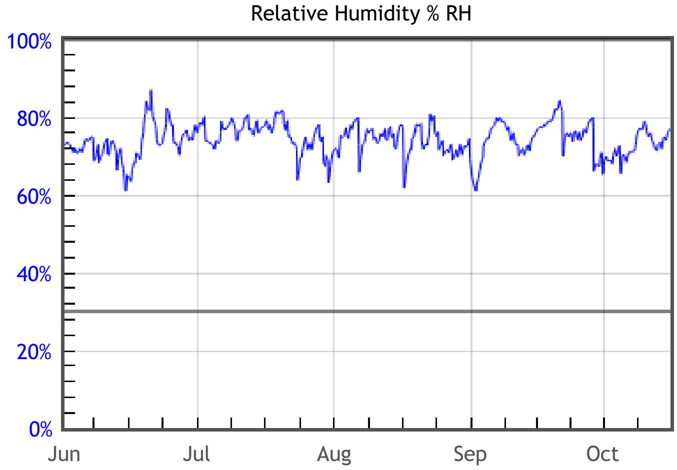
Type of Decay	Risks & Metrics	Evaluation & General Comments
Natural Aging Chemical decay of organic materials	RISK TWPI = 21	Accelerated rate of chemical decay in all organic materials due to the cumulative effects of temperature and humidity, with especially high risk for fast decaying organic materials such as acidic paper, color photographs and cellulosic plastics.
Mechanical Damage Physical damage to hygroscopic materials	RISK % DC = 0.32 % EMC min = 13.8 % EMC max = 15	Heightened risk of physical damage to any hygroscopic material, such as paintings, rare books, furniture, paper, leather, film, or color photos, due to extremely low or high levels of humidity, and / or excessive humidity fluctuation.
Mold Risk Mold growth in area or on collection objects	RISK MRF = 2.71	Heightened risk of mold growth due to extended periods of high humidity.
Metal Corrosion Corrosion of metal components or objects	RISK % EMC max = 15	Heightened risk of metal corrosion due to extended periods of high levels of humidity.

Graphs

Temperature °F



Relative Humidity % RH



Statistics

Temperature		Relative Humidity		Dew Point		T Limits		%RH Limits	
T°F Mean	68.8	**%RH Mean**	74	**DP°F Mean**	60.2	**T°F < 10**	0%	**%RH < 30**	0%
T°F Median	69.2	**%RH Median**	74	**DP°F Median**	60.9	**T°F [10,95]**	100%	**%RH [30,100]**	100%
T°F Stdev	4.6	**%RH Stdev**	4	**DP°F Stdev**	4.9	**T°F > 95**	0%	**%RH > 100**	0%
T°F Min	52.3	**%RH Min**	58	**DP°F Min**	44.6				
T°F Max	79.8	**%RH Max**	87	**DP°F Max**	71.8				

Gallery

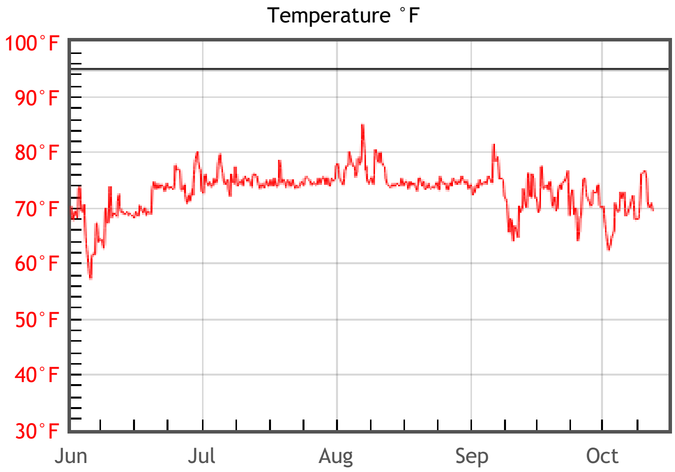
Monhegan Museum • Assistant Keeper's House • 1st Floor • Gallery
Monhegan Museum

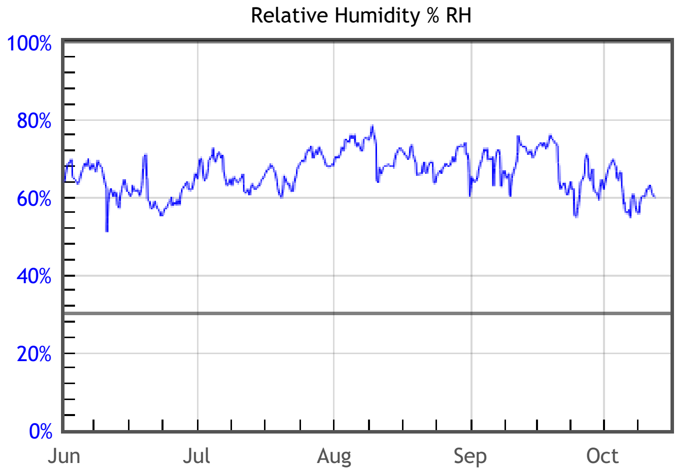
2018-06-01 to 2018-10-12
4 months, 12 days

Preservation Environment Evaluation

Type of Decay	Risks & Metrics	Evaluation & General Comments
Natural Aging Chemical decay of organic materials	RISK TWPI = 19	Accelerated rate of chemical decay in all organic materials due to the cumulative effects of temperature and humidity, with especially high risk for fast decaying organic materials such as acidic paper, color photographs and cellulosic plastics.
Mechanical Damage Physical damage to hygroscopic materials	RISK % DC = 0.53 % EMC min = 11.4 % EMC max = 13.3	Heightened risk of physical damage to any hygroscopic material, such as paintings, rare books, furniture, paper, leather, film, or color photos, due to extremely low or high levels of humidity, and / or excessive humidity fluctuation.
Mold Risk Mold growth in area or on collection objects	RISK MRF = 0.68	Heightened risk of mold growth due to extended periods of high humidity.
Metal Corrosion Corrosion of metal components or objects	RISK % EMC max = 13.3	Heightened risk of metal corrosion due to extended periods of high levels of humidity.

Graphs





Statistics

Temperature		Relative Humidity		Dew Point		T Limits		%RH Limits	
T°F Mean	73.1	**%RH Mean**	66	**DP°F Mean**	61.1	**T°F < 10**	0%	**%RH < 30**	0%
T°F Median	74.1	**%RH Median**	66	**DP°F Median**	61.8	**T°F [10,95]**	100%	**%RH [30,100]**	100%
T°F Stdev	3.9	**%RH Stdev**	5	**DP°F Stdev**	4.7	**T°F > 95**	0%	**%RH > 100**	0%
T°F Min	57.2	**%RH Min**	51	**DP°F Min**	46.4				
T°F Max	85.1	**%RH Max**	79	**DP°F Max**	75				

Monhegan Museum of Art History
Power Usage

Kilowatt readings								
Bill received in:	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
January	1500	2760	1130	1290	1350	1471	680	1180
February	1400	1210	1630	1130	1400	1600	620	1260
March	1020	1090	1420	1080	1389	1190	620	
April	1460	1149	1370	980	912	990	610	
May	970	871	910	1300	1039	840	590	
June	720	950	700	750	960	380	759	
July	870	850	660	1050	1210	510	2681	
August	1770	1140	1660	980	1540	359	5379	
September	2350	1280	1240	1550	1040	381	4431	
October	2440	770	970	970	870	980	1600	
November	2390	510	1021	780	1069	1120	1719	
December	2950	1150	1290	840	910	1196	1301	
TOTALS	**19840**	**13730**	**14001**	**12700**	**13689**	**11017**	**20990**	

Mechanical System Design Consultation And Preservation Commissioning

Monhegan Museum
Monhegan, ME

November 2018

Jeremy Linden, Principal
Linden Preservation Services, Inc.

Linden Preservation Services, Inc.
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PROJECT OVERVIEW

The Monhegan Museum contracted with Linden Preservation Services, Inc., (LPS) in September 2017 to complete the mechanical system design consultation and preservation commissioning work on their 2015-2018 National Endowment for the Humanities (NEH) Sustaining Cultural Heritage Collections (SCHC) Implementation Grant. LPS worked in conjunction with the Monhegan team, including Ronald Harvey, conservator, John Leeke, historic preservation consultant, and Innovative Construction & Design Solutions, LLC, engineering consultants, to implement sustainable solutions in several buildings at the Museum site to provide for improved long-term preservation using technologies sustainable to the island's setting. This consultancy built upon work performed by LPS Principal Jeremy Linden when he was previously employed with the Image Permanence Institute (IPI).

The final site visit was conducted on 12-14 June 2018; onsite work through the project consisted of walkthroughs of the individual buildings and storage environments, meetings to plan design and operation of mechanical renovations and new systems, and analysis of environmental data for preservation and energy operation. This report provides an overview of that work, including the final system installations, and assessment of the new systems' operation for preservation and energy, as the final deliverable in fulfillment of the consulting agreement. It was a pleasure to work with entire project team, and LPS remains committed to the possibility of working together with the Monhegan Museum and the project team to further refine operation and sustainable preservation moving forward.

Jeremy Linden
Linden Preservation Services, Inc.
December 2018

NOTE: Any views, findings, conclusions, or recommendations expressed in this report do not necessarily represent those of the National Endowment for the Humanities.

SITE INTRODUCTION

The Monhegan Museum is located at the top of Lighthouse Hill on Monhegan Island, ME, roughly twelve miles off the coast in Muscongus Bay. Its grounds include the historic Keeper's House and Lighthouse, the office and Gallery (modeled after the original Assistant Keeper's House), the Main Vault, and the workshop, and the Ice House Vault – formerly an exhibit space with collection storage above, and now fully dedicated to collection storage. The island, which measures roughly one square mile in size, must generate its own energy at a rate approaching ten times the rate on the mainland.

Aerial view of Monhegan Museum site, left, and Monhegan Power Plant, right.

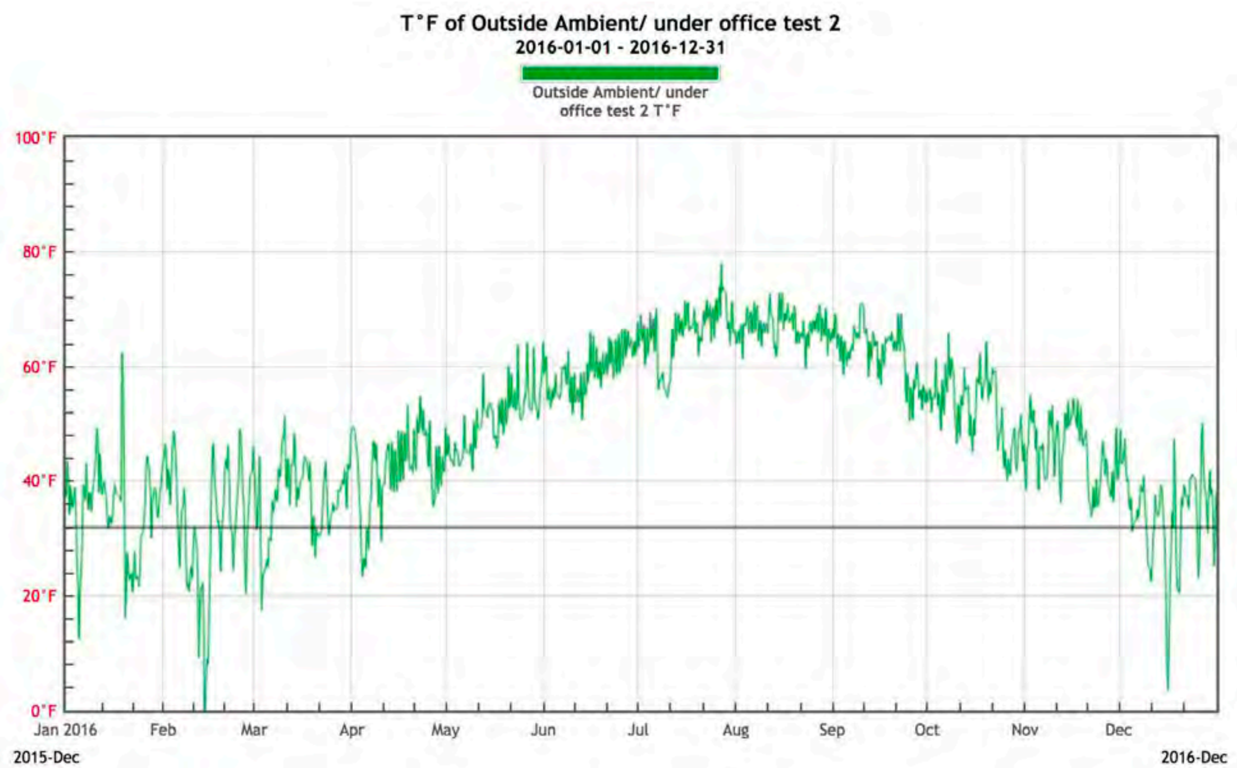
The facilities are a combination of modern and historic structures, with any changes in the appearance of the site generally governed by Maine Historic Preservation Commission requirements. Prior to the implementation project, environmental control at the site was fairly limited in scope and capability:

- The Main Vault had both temperature and relative humidity (RH) control, with mechanics located in a shed at the rear of the building;
- The Ice House Vault had temperature and RH for the collection storage on the upper floor; the lower floor was unconditioned exhibit. Mechanics were located in a shed at the rear of the building.
- The Office/Archives was served by propane wall heaters for winter occupancy.
- The Gallery and Keeper's House were completely unconditioned.

As reported in the 2015 Final Report from Jeremy Linden/IPI for the NEH SCHC Planning Grant, each of these spaces had particular environmental challenges which posed various risks, either to the appropriate preservation of the collections stored or exhibited in the space, or to the long-term sustainability of the controlled environments. The implementation project addressed issues in each of the five primary spaces.

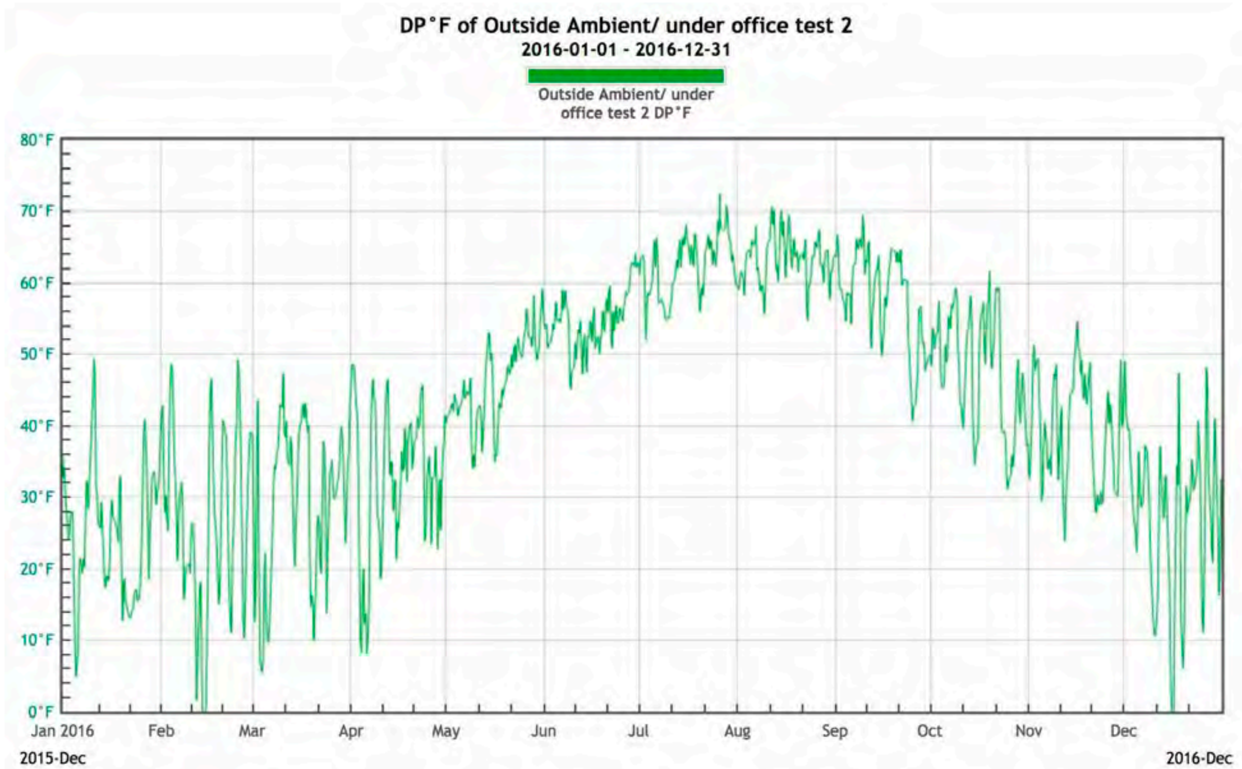
General Monhegan, ME, Weather Conditions

Monhegan, ME, experiences a seasonal environment marked by warm, humid summers, and cold winters that are largely influenced by the surrounding conditions of Muscongus Bay. Weather conditions are typically markedly different than the mainland, and analysis of island environments must rely on data gathered on-island. Summer high temperatures typically average in the low 70s, with occasional days spiking near 80, while winters will regularly drop below freezing conditions, with occasional weather systems pushing temperatures below 20F. Outdoor dew points vary with the season, with conditions above a 50F dew point approximately 40% of the year. Low dew point conditions rarely drop below 10F due to the proximity of open water year round.



Monhegan, ME, Lighthouse Hill - Temperature Graph, 2016. Limit line is at 32F.

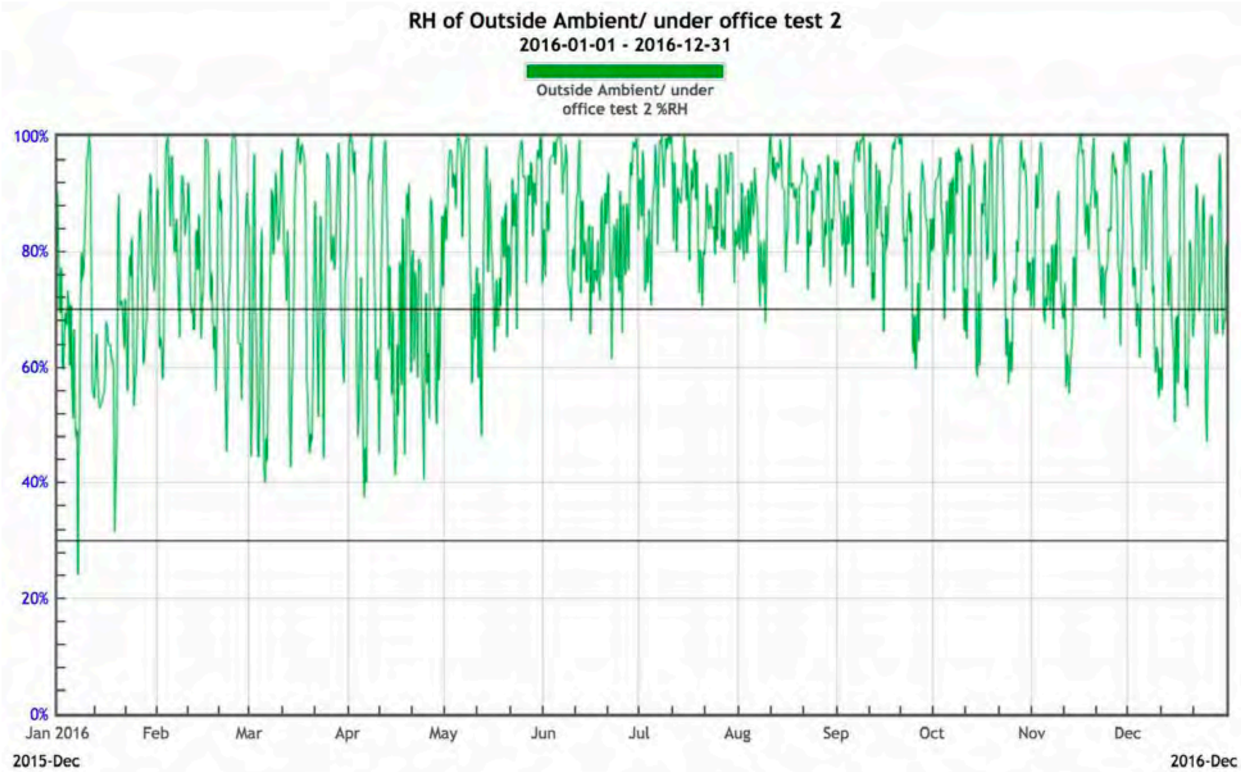
Depending on the preservation conditions desired, this exterior environment commonly requires four distinct modes of mechanical operation in order to maintain an appropriate interior environment for long-term preservation of cultural heritage materials: sensible heating, sensible cooling, dehumidification, and humidification. The time that the systems spend performing each operation will largely depend on the interior and exterior heat and moisture loads as well as the desired interior preservation environment. In the case of the Monhegan Museum, these loads and interior environments vary considerably from one building to the next due to envelope considerations, the influence of outside air incursion, and the varying environmental expectations for different spaces.



Monhegan, ME - Dew Point Graph, 2016.

In addition to the capacity of the mechanical system to handle these operations, the physical structure of a building must be designed and constructed to mitigate differences between temperature and moisture conditions between the interior and exterior of the building. For purpose-built cultural heritage facilities this generally requires the use of both thermal insulation as well as a specific vapor barrier within the wall, roof, and slab construction. The greater the difference between the desired preservation condition and the exterior environment, and the greater the desire to minimize the energy input into interior environmental control, the more critical the need for specialized construction. Moisture control (dehumidification and humidification) in buildings without vapor barriers can lead to significant damage – both aesthetic and structural – over time.

From a temperature perspective, conditions on the island are generally favorable for collections preservation – long periods of cool temperatures (50F and below) allow for the potential of minimal mechanical intervention, and high temperatures are rarely a significant issue save in building locations where radiant energy from direct sun raises the interior temperature. The primary preservation issue for Monhegan is the fact that open water results almost constant high RH conditions year-round. A comparison between RH data gathered from Lighthouse Hill compared to data from Rockland, ME (on the mainland) shows that, for 2016, Lighthouse Hill was above 70% RH – a typical starting point for mold germination – nearly 78% of the year, while Rockland was above 70% RH for 64% of the year.



Monhegan, ME - RH Graph, 2016. Limit lines are at 30% and 70% RH.

The result of these RH conditions has traditionally been a high risk of mold growth, particularly in the Museum areas that are completely unconditioned. The Keeper's House, which is closed each winter season, has had issues with mold growth each spring on certain walls of the house, and mold germination was documented on the verso of an artwork hanging in the unconditioned Gallery in 2014. These ongoing issues, and the potential risk to both collections and the buildings, was critical component in exploring solutions during the implementation project.

Setting Preservation Goals

Understanding Environmentally Driven Degradation

The appropriateness of the interior environment for preservation largely depends on the particular usage of the space/zone and the preservation quality necessary for the materials in question. The goal of environmental control in cultural heritage settings is to minimize risk of degradation due to inappropriate temperature and RH conditions, which cause four primary types of damage:

- Chemical decay – the natural degradation of organic (carbon-based) materials over time, driven by temperature and relative humidity; generally, cooler temperatures at moderate relative humidities extend the life of collections;
- Mechanical decay – physical shape-change of hydrophilic materials based on fluctuating moisture contents. High RH levels can cause materials to expand or swell, straining the physical structure, while low RH conditions can cause materials to shrink or split. Safe ranges vary for different media, but broad limits between 30-60% RH provide an initial starting point;
- Biological decay – as a general definition, any damage caused by living organisms, such as mold growth or damage due to pests. Risk is primarily driven by RH levels, however temperature does influence rate of mold germination as well as reproductive cycles for pests. Keeping RH below 70% will effectively eliminate mold risk;
- Metal corrosion – oxidation of certain metals, particularly iron (and steel), silver, copper, and bronze, driven by high RH levels over periods of time. Metallic components regularly occur even in rare book and archival collections, most significantly as part of silver-based image collections. Iron gall ink degradation, though not technically an oxidation reaction, is similarly driven by high RH conditions. Oxidation points for individual metals vary, but for most materials, keeping RH below 55% will minimize risk.

Past preservation and control strategies for collections environments advocated for "flat-line" control of temperatures and RH in order to limit perceived damage due to fluctuating conditions. Materials science research – performed by the Smithsonian Institution, the Canadian Conservation Institute, the Image Permanence Institute, and others – has since proven that most materials can be safely preserved within a range of temperature and relative humidity conditions, and that "flat-line" control is not only unsustainable from an energy and operational perspective, but may actually miss opportunities for improved preservation quality in certain circumstances.

Application of Collections Risk to Building Operation

Design conditions for building operation and environments for collections preservation should always consider the unique nature of the individual institution, including:

- The preservation needs of the collection and of the building (if applicable);
- Its geographic location;
- Prevailing weather conditions;
- Structural design and integrity;
- And mechanical infrastructure (both existing and potential), among others.

Historically, the preservation profession has placed a premium on controlling preservation environments to tight standards, generally at human-comfort temperatures (70F) or cooler. While materials science has shown that cool temperatures and moderate relative humidities are best for most collection materials, the achievement of those conditions must be balanced against the ability and situation of the institution. For many institutions in historic structures (regardless of whether those structures have unique historic significance), preservation priorities must be adjusted based on resources, infrastructure, and the need to simultaneously preserve the building in addition to the collection. Initial goals should often be driven by significant risks – avoiding mold growth and damage to the building structure, achieving appropriate pest control, and staying within an affordable energy budget.

Defining Preservation Goals for the Monhegan Museum

The Museum's collection includes a broad variety of items spread among the individual buildings – fine art, ranging from oil and acrylic on canvas to watercolors on paper, library and archival materials including photographs and acidic papers (both manuscripts and bound volumes), natural history specimens, and cultural artifacts of various media, including composite objects of wood, metals, and plastics. That breadth, combined with realistic expectations for environmental control for each structure in the island environment, and the critical need for the solution to be sustainable from an energy and maintenance perspective, were the key factors in identifying environmental goals on site.

The selection of the design parameters for environmental goals in the various buildings was based on those blended factors of avoidance of risk to collection materials, flexible environmental conditions that would minimize energy consumption, and minimizing mechanical intervention where possible. Potential preservation goals had been discussed through the NEH Planning Grant period, and in 2016 the team agreed on the following design goals:

- **Main Vault**: Temperature and RH fluctuate with the seasons to allow for slower rates of chemical decay during winter and reduced energy expenditure during the summer. Because the vault had always been mechanized the goal was to update the systems and controls.
  - Temperature: 70F summer max
    45F winter minimum (to protect oils and acrylics)
  - RH: 55% summer max
    30% winter minimum (passive, no humidification)

  These conditions would require summer cooling and dehumidification, and winter heating to maintain the minimum temperature. Keeping the temperature low also helps to maintain RH conditions above 30%.
- **Ice House Vault**: Temperature and RH fluctuate with the seasons to allow for slower rates of chemical decay during winter and reduced energy expenditure during the summer. The upper level of the Ice House Vault was already fitted out as collections storage with environmental control; the implementation project both renovated the lower level for collection storage – thermal insulation, vapor barriers, and finished walls, a new door, and insulation and a vapor barrier under a new floor – as well as updated the existing mechanical system to provide appropriate conditions for both levels.
  - Temperature: 70F summer max
    45F winter minimum (to protect oils and acrylics)
  - RH: 55% summer max
    30% winter minimum (passive, no humidification)
- **Office/Archives**: Temperature and relative humidity fluctuate based on season and occupancy to balance preservation needs with human comfort. The Office area had been served by propane heaters for winter comfort, but no summer environmental control; the goal with the new system design was to explore other technologies for more sustainable heating, while also providing for dehumidification during the summer months.
  - Temperature: 72F summer max

68-70F winter max (when occupied)
55-60F winter minimum (to allow recovery of heat for comfort)
    - RH: 55% summer max
Variable winter RH (no humidification)

- **Gallery**: Temperature and relative humidity fluctuate based on season and the nature of the particular show/exhibit. Summer operation, when collections are present in the space, should be capable of set points that can vary based on any loan requirements. Winter control was deemed unnecessary due to the removal of collection objects from the space. Any mechanical intervention would be new, and based primarily on the need to mitigate summer risk due to high RH.
    - Temperature: 72F summer max for loan conditions
No temperature control in winter.
    - RH: 50% +/- 5% for summer loan conditions.
55% summer max for all materials.
No RH control in winter.
- **Keeper's House**: Initially, no mechanical intervention was planned. Technology selected for the rest of the site created an opportunity to provide a small amount of heat to the Keeper's House basement in an effort to limit high winter/spring RH conditions in the building.
    - Temperature: 40F winter set point.
No temperature control summer.
    - RH: No RH control.

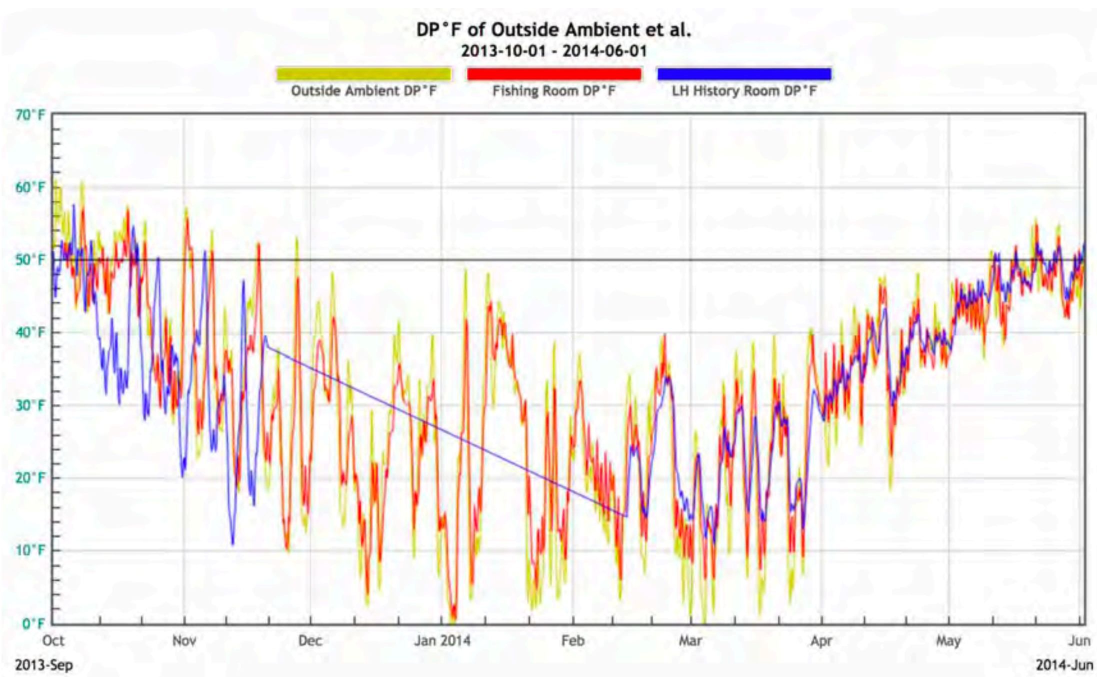
STRUCTURAL WORK AND IMPROVEMENTS

The Structure as the First Level of Environmental Mitigation

An appropriate building envelope – including walls, roof, windows and doors, and any foundation or sub-grade structure – should be considered the first priority of creating and maintaining interior preservation environments for cultural heritage, both because of its critical impact on the long-term energy usage, but also due to its ability to inherently limit interior capabilities, especially when working with historic structures. Goals for preservation at the Monhegan Museum had to be carefully considered in relation to the individual structures – Monhegan staff and the team acknowledged early in the process that appropriate environmental management in the Keeper's House was a very different mission that the mitigation of degradation risks in the other buildings. In addition to the Keeper's House, significant changes were made to the interior structure of the first floor of the Ice House, both in envelope improvements for environmental control as well as to fit it out for collections storage.

Keeper's House

Historically the Keeper's House was heated with standing radiators, which had been previously removed. In the staff's memory and experience, the structure had always been fully unconditioned. Each year, a number of collection objects are removed from the exhibit at the end of the summer season and placed in storage for winter. Spring commonly finds mold/mildew growth on certain walls, which are cleaned before collection items are replaced in the exhibit. Initial plans during the planning and early implementation phases were to avoid any mechanical intervention in the Keeper's House, and only rely on structural improvements – windows, foundations, flooring, and doors – to mitigate seasonal environmental issues.

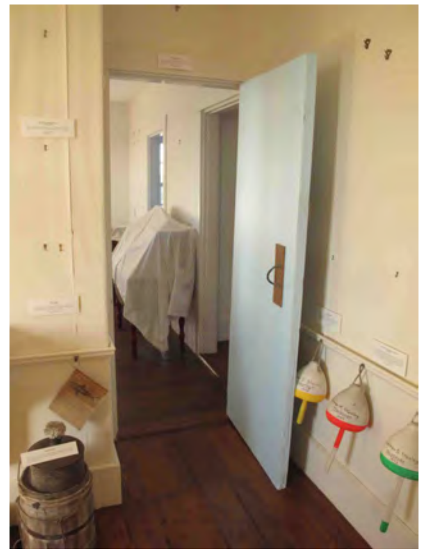


*Keeper's House Dew Point, 2013-2014. Note that interior dew points (blue and red) tracked with outdoors (yellow) in fall 2013. After installation of door panels in the LH History Room, the space no longer responded to the full exterior dew point changes in winter/spring 2014. *An incorrect datalogger time code in the fall of 2013 shifted data points to ~two weeks earlier than actual recordings.*

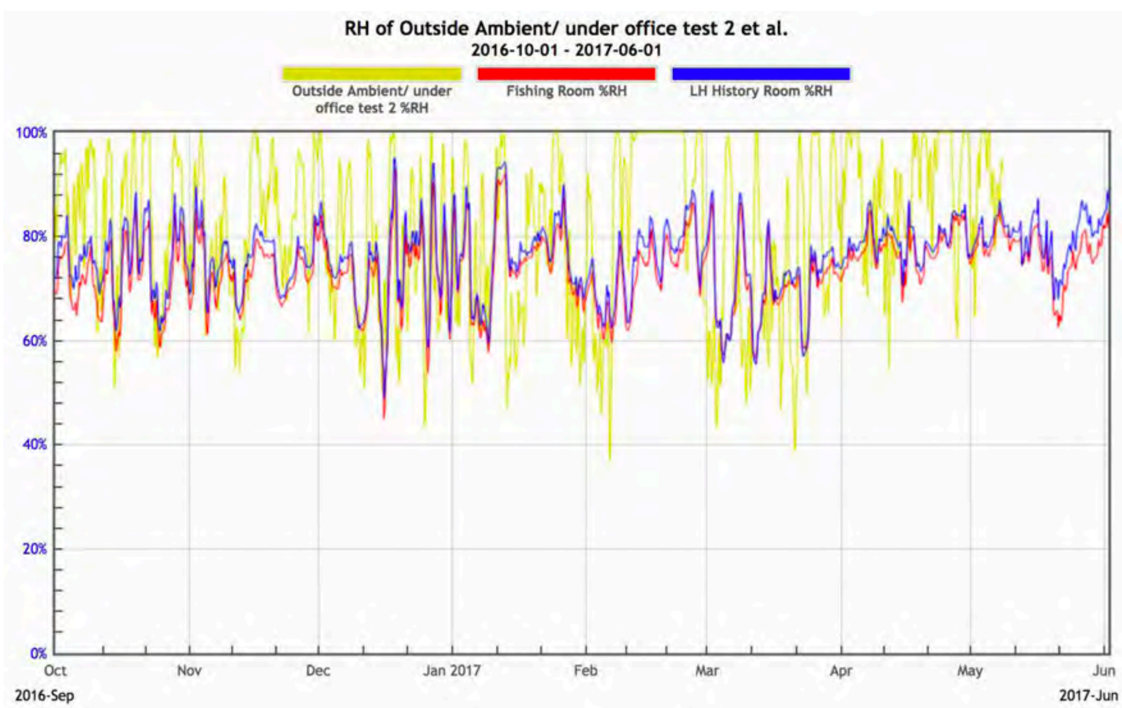
Early environmental data gathered from the Keeper's House showed that the interior dew point and RH tracked very similarly to outdoor conditions – gaps in the foundation, holes in the interior floor (largely from original radiator locations), and water incursion in the basement all meant that exterior moisture conditions could rapidly influence the interior environment. Repairs were made to the historic structure and site over the course of the project that had a distinct impact on the management of the interior environment, specifically including:

- The use of insulated panels in doorways during the winter months to restrict moisture movement;
- Rehabilitation and repair of the windows in the Keeper's House;
- Filling of existing holes/gaps in the floorboards between the basement and the first floor;
- Filling of gaps in the basement foundation;
- Rerouting roof drainage and runoff around the building structure, to reduce moisture in the basement.

In addition, an open water holding tank in the basement was replaced with an enclosed tank to eliminate evaporation issues which were contributed to building moisture and causing significant issues with condensation, oxidation, and mold growth in the basement space.



Insulated door panel between the Fishing Room and the History Room.

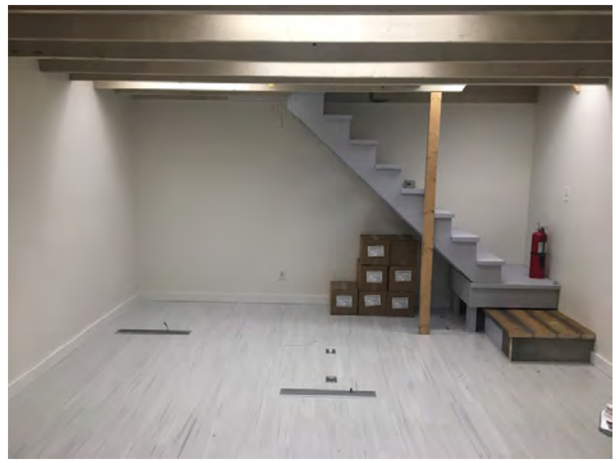


Keeper's House RH Graph, 2016-2017. Note the muted RH plot compared to outdoor conditions, primarily as a result of consistently lower dew points.

During the winter of 2016/2017, when a number of these improvements were underway, the interior dew point during the winter months was successfully muted compared to outdoor conditions, which resulted in RH conditions that, while still high enough to cause concern for mold germination, were consistently lower than the high outdoor extremes. The completion of most of the structural repairs between 2017-2018, combined with the head added to the basement in fall 2017, resulted in no mold growth in the first floor of the Keeper's House in the spring of 2018.

Ice House

The structural renovation of the first floor of Ice House provided the most efficient solution to a significant need for increased collection storage, including additional art racking and a freezer for preservation of acetate film and color photography. The structural renovation specifically included rigid-foam thermal insulation in each individual joist space, finished with drywall, to provide both insulation and a vapor barrier for the space in order to reduce the energy load. The under-floor crawlspace had plastic added as a vapor barrier as well as a layer of thermal insulation. At the time of the final onsite visit, the final structural addition was fitting the custom-built door with a sweep and gaskets to block the air gaps.



The renovated Ice House first floor - all walls were constructed with additional thermal insulation and a vapor barrier to minimize the energy load on the space.

Gallery

The Gallery did not receive any significant structural work during the project. Before electing to provide summer dehumidification to the space, the team determined that the original construction likely included enough thermal insulation and a sufficient vapor buffer to allow for effective conditioning and control.

A leak was discovered at the upper southeast window during the initial visit. The leak may have been the cause of the moisture issues along this wall; evidence of minor water damage was visible on the exterior crawlspace windows and on the floor joists in the crawlspace. The leak was repaired, and no further signs of moisture incursion were seen during the course of the project.

Office

No significant structural changes were made to the Office over the course of the project. Like the Gallery, the team determined that the thermal insulation and vapor buffering of the original construction were sufficient to allow for summer dehumidification and environmental control.

Main Vault

The Main Vault did not receive any structural changes or improvements over the course of the project.

Mechanical Design and Installations

Mechanical renovation at the Museum was necessitated by several complimentary factors – both the Main Vault and the Ice House upper floor were running on the original systems which, after 15+ years in the island environment, had lost a portion of their capacity for dehumidification and were mechanically in need of replacement. Additionally, the original controls for the units, while state-of-the-art when installed, could only be operated from a panel at the unit itself, making operational adjustments for optimization of preservation and energy virtually impossible. The need for additional storage necessitated increasing the capacity of the Ice House unit, and the Museum staff had noted several issues over the years with obtaining loaned materials for their summer Gallery exhibitions.

The Monhegan Plantation Power District's (MPPD) concurrent replacement of its diesel generators with diesel micro-turbines provided a unique opportunity for shared benefit to both the Power District and the Museum. The addition of a heat-recovery module to the units allowed the waste heat from the generation process to be captured and applied to a hot/water glycol loop (referred to as "hot water" hereafter); by piping the hot water/glycol roughly 200 yards down the hill to the Museum site, heat was available for both summer dehumidification as well as winter heating. The use of the waste heat from the microturbine not only improves the overall efficiency of those units – without heat recovery the units is only ~30% efficient, with the heat recovery in place, the efficiency pushes ~80% – but also, depending on the negotiated rate with the MPPD, provides the Museum with a less expensive heat source compared to fully relying on propane.

Overall, the systems design at the Museum site is based on a series of potential energy sources, with the most sustainable options as the primary option, and the least sustainable as the final backup option. Typically, conditioning the interior environments is based on utilizing hot water for heating, chilled water/glycol (referred to as "chilled water" hereafter) for cooling, and desiccant dehumidification with hot water regeneration. The crawlspace beneath the Gallery serves as an accessible central systems area, from which hot and chilled water are served to the necessary locations on the site:

- Chilled water: provided by two MultiAqua air-cooled chillers for redundancy, running on a lead-lag control (chillers run on a weekly alternating schedule – one is operating while the other is offline). Chilled water is only used for sensible cooling, which significantly reduces the total energy load compared to using it for subcool/reheat dehumidification.
- Hot water: supplied from one of three potential sources, in the following order of preference:
    - Solar thermal collectors: a solar array installed on the south-facing office roof uses solar energy to heat a hot water/glycol solution, which is then transferred to a buffer holding tank. If hot water from the solar thermal is available (based on sun exposure – which is possible even in winter months), this system takes precedence in providing hot water to the site.
    - Microturbine heat recovery: the recovered heat from the microturbine generators is considered the "primary" source of hot water; if the solar thermal is available it becomes the primary.
    - Propane-fueled boiler: the backup heat source for the entire site; in the event that the solar thermal and the heat recovery are not sufficient to provide heat, the boiler will activate to provide the minimum hot water necessary. Potential causes for boiler

use may include a mechanical malfunction with the microturbines that would render the heat recovery unavailable, or the potential of insufficient electrical demand during winter months (when the island has a low population) resulting in little available heat recovery.

Dehumidification is provided by individual desiccant units at each location – the Main Vault, the Ice House Vault, the Gallery, and the Office. The regeneration energy is provided by hot water; during the summer months this source should typically be the solar thermal or the heat recovery. A portion of the return air from each space is routed to the desiccant unit, dehumidified, and fed back into the return air stream to be sensibly cooled before being supplied to the space. The regeneration air is pull from outdoors, heated by the hot water to evaporate moisture from the desiccant wheel, and then exhausted away from the unit.

In total, the project installed/replaced four air handlers, each paired with a desiccant dehumidifier:

- **Main Vault:** The new unit replaced the original system in the mechanical shed at the rear of the building. No ductwork was changed as part of the renovation. The primary unit includes a hot water heating coil and chilled water cooling coil, with the desiccant dehumidifier installed on the return air side.
- **Ice House:** The new unit replaced the original system in the mechanical shed at the rear of the building. Ductwork to the upper level was unchanged; additional ductwork was added to serve the renovated first floor. The primary unit includes the chilled water cooling coil; two separate in-duct hot water heating coils serve each of the two levels. The desiccant dehumidifier is installed on the return air side of the primary unit.
- **Office:** The new unit is located in the crawlspace directly below the Office. The original propane heaters were removed and new ductwork was added to serve the area. The primary unit includes a hot water heating coil and chilled water cooling coil, with the desiccant dehumidifier installed on the return air side.
- **Gallery:** The new unit is located in the crawlspace directly below the Gallery. Ductwork was added to both the Gallery space as well as to the Porch area. The primary unit includes a hot water heating coil and chilled water cooling coil, with the desiccant dehumidifier installed on the return air side.

Environmental Assessment – Preservation and System Operation

Environmental monitoring of the Museum's collections spaces – both storage and exhibit – started with their 2011 NEH Preservation Assistance Grant. Datalogging of the mechanical systems began with the 2013 NEH SCHC Planning grant and has continued through the Implementation project, with the exception of some minor data gaps due to the system replacements. Loggers are still in place as of the writing of this report in December 2018, and will remain in place for the foreseeable future.

While heat from the new system was available beginning in November 2017, full system startup and final controls commissioning for the Museum site occurred in the summer of 2018 (chillers were brought on line during the June 2018 onsite visit). ICDS noted that there were several issues with the MPPD plant being offline over the course of the summer of 2018 – one critical operational note is that the diesel backup generators used for island power when the microturbines are down do not power the Museum chillers, which results in a loss of cooling during those periods. With data from only summer and fall, and several lapses in cooling due to the power plant being offline, the ability to fully analyze the preservation and operational impact is limited – observations are based on available data, with recommendations for potential control adjustments and experimentation to begin in the summer of 2019.

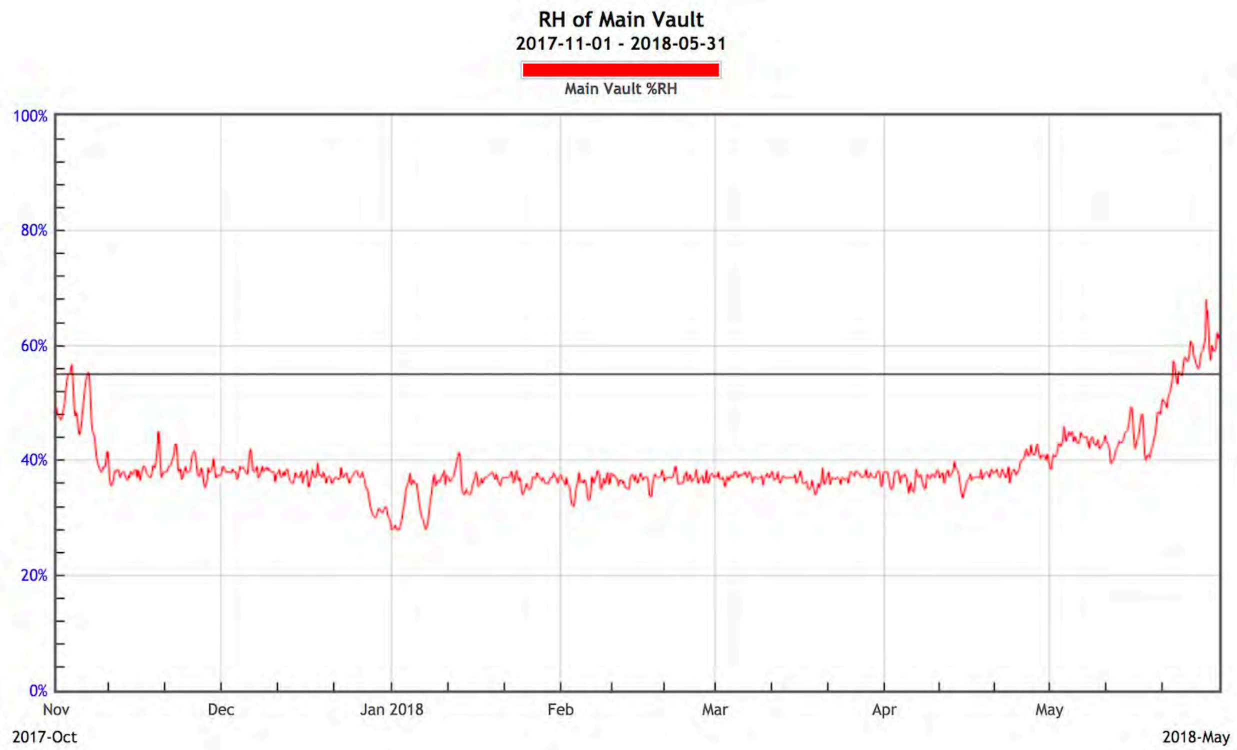
Main Vault

The Main Vault is covered by a total of four mechanical loggers – supply air, return air, dehumidified air, and cooled air – as well as a single environmental logger in the space. Environmental goals were:

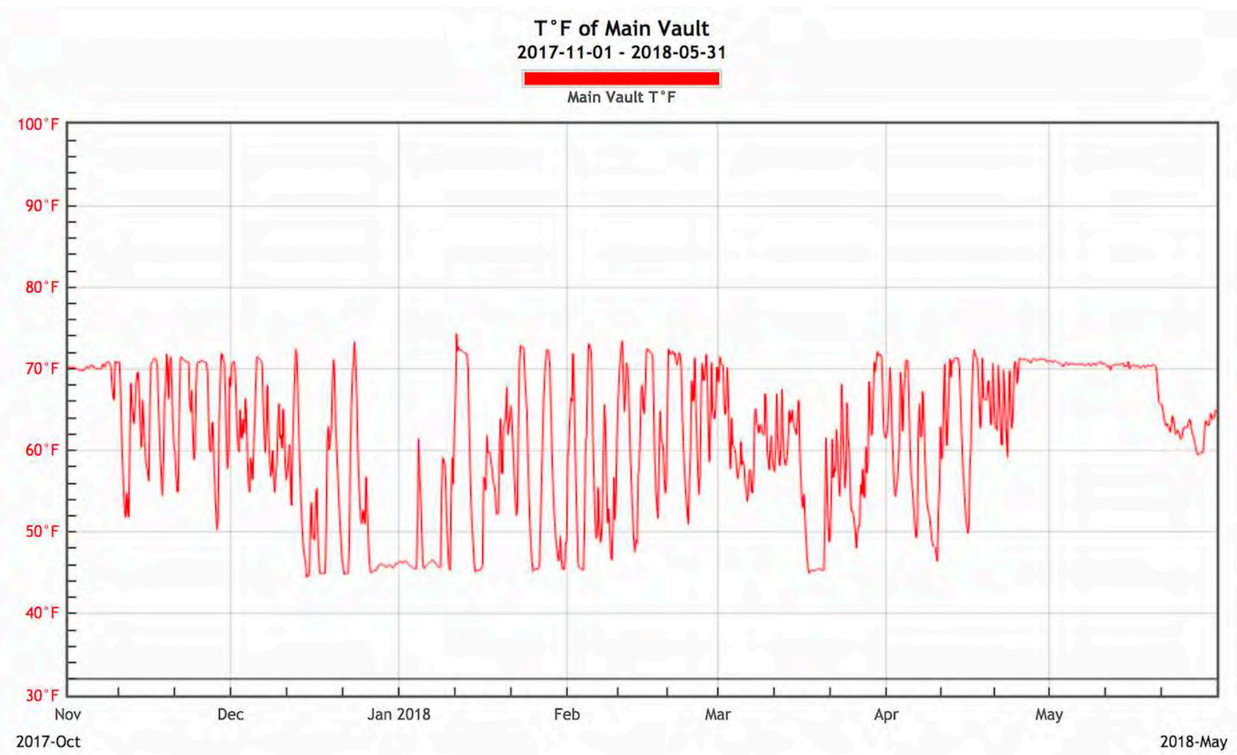
- Temperature: 70F summer max
  45F winter minimum (to protect oils and acrylics)
- RH: 55% summer max
  30% winter minimum (no humidification)

These conditions, if achieved, would combine reduced seasonal energy consumption with improved preservation over the course of the year – cool winter conditions bring down the overall rate of chemical decay, while the seasonal RH swings are kept within safe limits for the collections materials.

The programming for winter operation, and the behavior of the interior environment, shows a standard humidistatic control (commonly known as "conservation heating"). The basic logic is that the system is controlled to maintain a specific RH condition by controlling the temperature in the space – when the RH begin to rise, the temperature is increased to bring it down, while when RH is steady or begins to drop, the space is allowed to cool down in order to raise the RH. The result, shown in the graphs below, is a very steady RH condition in the space, and temperatures that fluctuate regularly (and significantly).



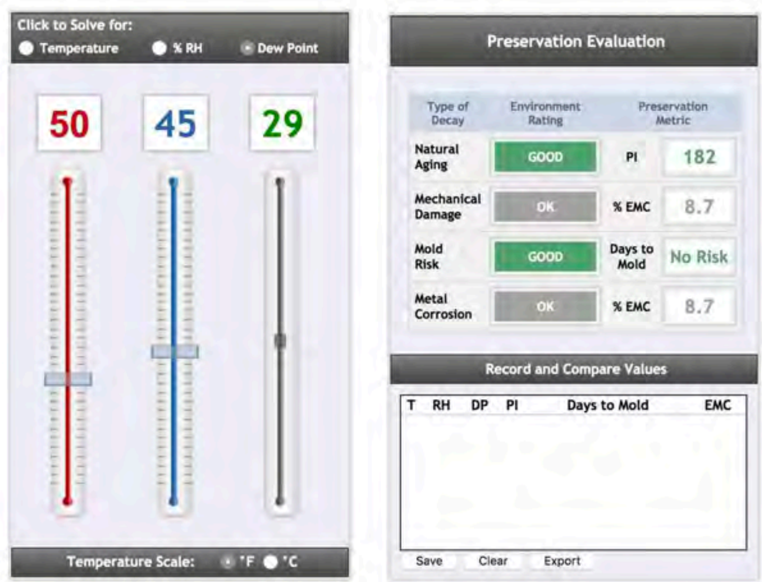
Main Vault, RH Graph - Winter 2017-2018. Note flatline control of RH condition.



Main Vault, T Graph - Winter 2017-2018. Note fluctuation in order to maintain the above flatline RH condition.

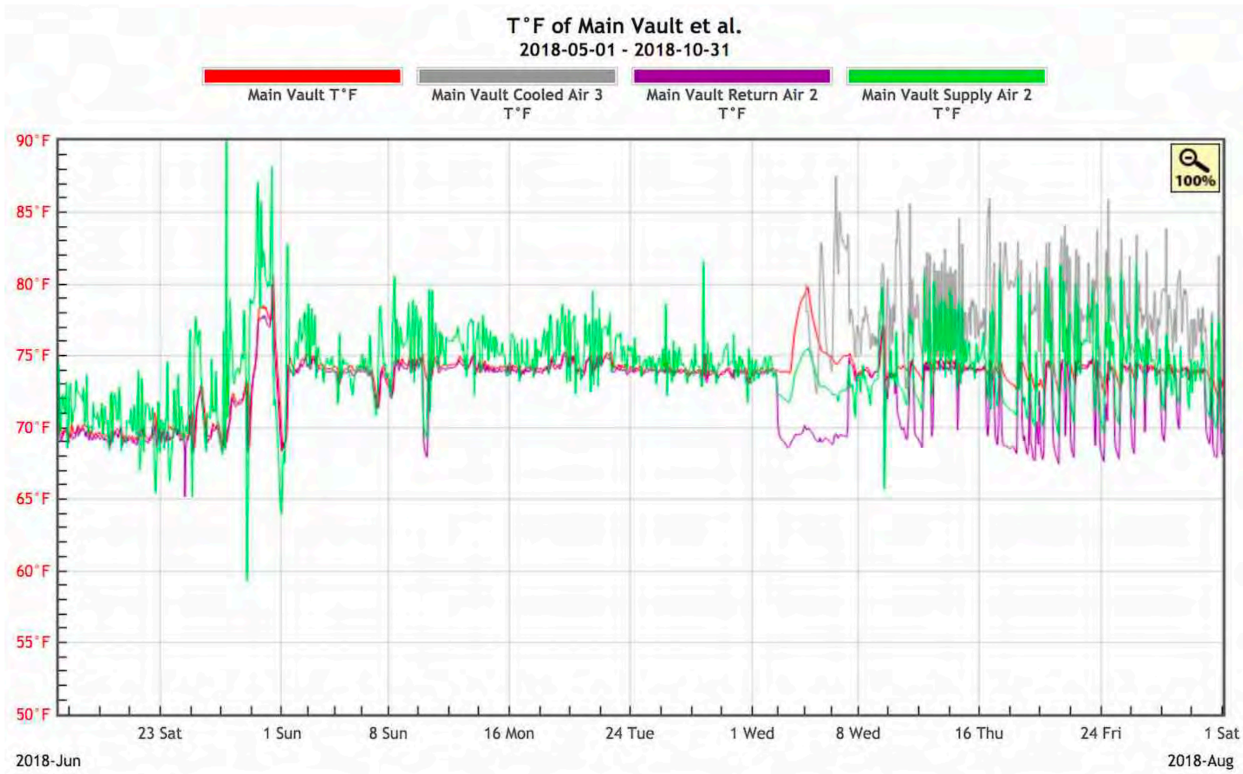
While humidistatic control is appropriate in various settings – most commonly when the goal is to avoid mold germination conditions or to maintain steady RH conditions to protect against mechanical damage – the primary winter concern for the Main Vault is to keep the temperature condition as low as possible (45F minimum) while keeping the RH conditions within an acceptable band (the seasonal 30-55% range). These conditions have the dual benefits of slowing the rate of chemical decay through cooler winter space temperatures, decreasing energy costs by minimizing heating, while still maintaining a safe RH band for protecting against mechanical damage.

While optimization of the control should still be accomplished, overall preservation quality was still good for the winter of 2017-2018, with a time-weighted preservation index (TWPI – a metric for rate of chemical decay) of 87, just better than the TWPI of 85 achieved in the winter 2015-2016. If the optimized control can allow the space to drift toward 45-50F more consistently, the winter TWPI for the Main Vault should be able to approach TWPIs of 140 or better – a significant improvement over previous conditions – with reduced energy consumption. Outdoor conditions between January and April 2018 were steadily below 50F, and the illustration at right shows an example preservation quality if 50F and 45% RH were maintained in the Main Vault during those months.



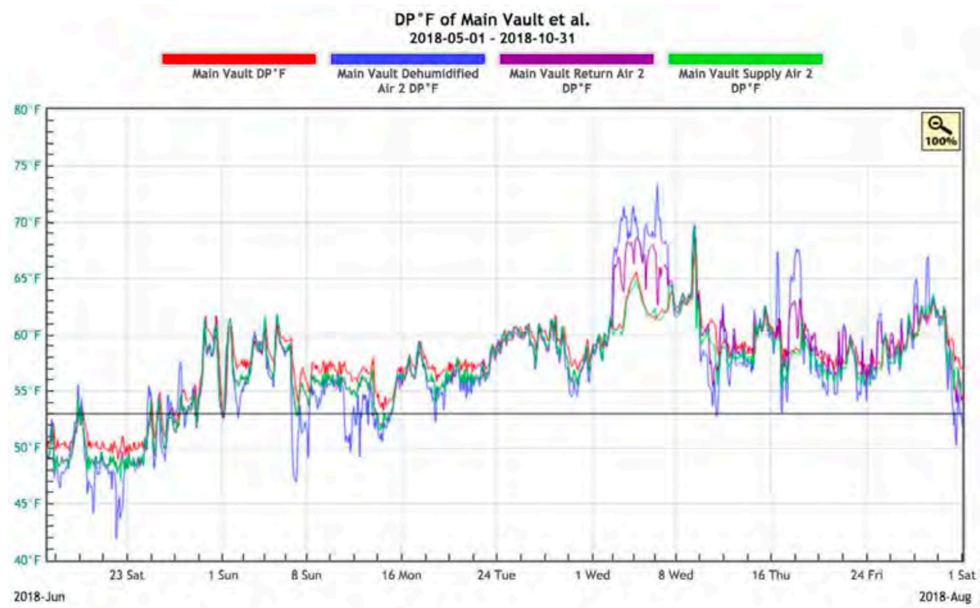
Dew Point Calculator (DPCalc) illustration of potential preservation index (182) at a 50F/45% RH condition. This condition is representative of an average winter condition that should be achievable with the new system and controls.

Space temperatures during the summer 2018 season ran slightly higher than the originally intended 70F condition, which is likely simply the result of a higher set point. Supply and return air conditions from the system indicate very little load from the Main Vault itself – return air comes back at the same condition as the room, while the supply air is, surprisingly, somewhat warmer (1-5 degrees F on average), actually appearing to be heating. That warmer supply air condition is most likely due to the power plant/chiller issues (ie, there simply was not chilled water available to create a cooler condition). Less likely is the possibility that the apparent 75F set point was actually high enough that the system minimized cooling in order to keep the temperature artificially higher compared to outdoors – though this is common in other buildings and environments, it is currently unclear whether the control logic would allow this to happen. A drop in temperature from the cooled air temperature to the supply air temperature indicates that the unit was not actively heating with hot water during this period.



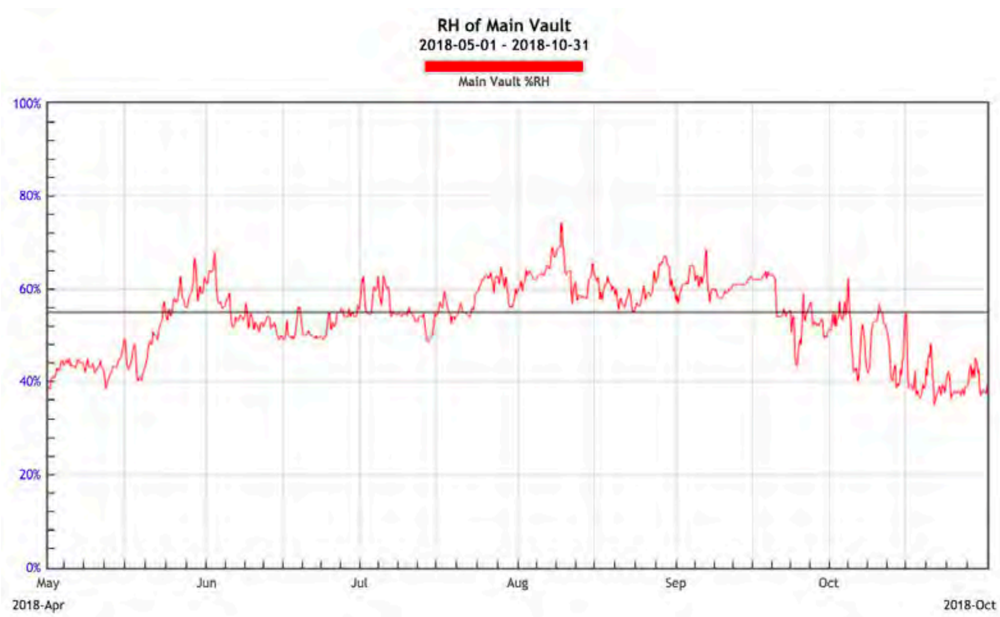
Main Vault, T Graph - Summer 2018. Note minimal difference between supply air and return/space temperature. Though cooled air data is missing for much of the summer, the grey plot in August does show limited sensible cooling operation.

Of greater concern is the fact that the dehumidifier did not seem to be holding the RH limit during the summer season. Using the dew point graphs as a starting point, there is an apparent lack of dehumidification – the difference between the space dew point and the dehumidified air/supply air dew point is typically less than 2F. If dehumidification operation is dictated by RH conditions, the supply dew point is expected to fluctuate somewhat, based on what the space temperature may be. However, in peak summer season, the expectation is that the space temperature will commonly be close to the set point condition, and that the system will have to dehumidify to a particular dew point condition due to the high ambient dew points outdoors. The graph below shows the dew point plots for the Main Vault and the return, supply, and dehumidified air conditions, will all track quite closely. If the RH maximum condition of 55% were being maintained at 70F, the space dew points should track closer to at a 53F dew point condition, represented by the displayed limit line. Even at the current ~75F set point, a max 55% RH condition would result in a 57F dew point condition, still lower than the typical summer operation.



Main Vault, DP Graph - Summer 2018. Note the minimal dehumidification and close tracking of the conditions. If running appropriately, the space dew point (red plot) should track closer to the displayed limit line.

The result space RH condition, shown in the graph below, is consistently higher than the max 55% condition during the peak of the summer season. While these conditions are not a threat for mold growth, there is a small risk of mechanical shape change based on the higher RH and length of time at those conditions, and a significant risk for oxidation of metallic elements in the storage environment. The warmer-than-desired temperatures, combined with higher RHs, slightly increased the overall rate of chemical decay compared to the design intent (summer design PI was 34, actual performance was a TWPI of 30).



Main Vault, RH Graph - Summer 2018. RH conditions are regularly higher than the 55% max design condition.

Main Vault Recommendations

Adjustments in control, further investigation into the operation (or lack of) of the dehumidifier, and improved cooling availability should allow the Main Vault environment to fall within the environmental design targets. The following are suggestions for initial controls adjustments. Please note that these are broad guidelines based on past discussions of desired preservation and operational goals – the Monhegan staff and team should discuss final conditions and any limitations based on the installed mechanical and controls system.

- Heating: can be enabled based on either of two conditions:
  - The space temperature drops below 45F. At that point, engage the heating until the space temperature reaches 50F. Heating shuts off until a call for heat at below 45F.
  - The space RH goes above 55%. At that point, engage the heating until the space RH reaches 50%. Heating shuts off until RH goes above 55% again. This action is only enabled when the chillers and dehumidifiers are offline (presuming that the chillers are taken offline for the winter).
- Cooling: is enabled based on one of the following two conditions:
  - The space temperature goes above 70F (adjustable), with or without dehumidification operation.
  - Whenever there is a call for dehumidification, cooling is enabled to sensibly cool the blended return/process air condition to the appropriate supply air condition (based on space temperature).
- Dehumidification: is enabled based on the following condition:
  - The space RH goes above 55%. At that point, dehumidification is enabled either to maintain 55% or until the space RH condition reaches 50% (or a lower selected condition). Dehumidification can be enabled at any temperature condition, provided that the chillers are online and available to sensibly cool the blended return/process air condition.
- Circulation/fan operation: is enabled "on" until consistent set point maintenance is achieved.

If successful, these set points and operations should result in a yearly band of temperature in the space between 45-70F – if the space temperature is within those ranges, no sensible temperature control should occur unless cooling is enabled for dehumidification. Likewise, the yearly RH band should stay below 55% and typically above 30% - based on historical winter dew point conditions inside the Main Vault, low dew point conditions do not generally drop below 20F which, at a 50F interior temperature (presuming that the low dew point condition will be accompanied by a cold outdoor temperature, and a call for heat) is still a 30% RH. Historically, any cold weather events cold enough to drop the indoor dew point below 20F have been for relatively short periods of time (three consecutive days in February 2014, and a week in January 2018), with interior RH conditions that did not drop below 25% RH.

Note that these control adjustments do not account for unit scheduling (ie, shutdown testing) or setbacks in operation for the purpose of additional energy savings. Once the unit and controls have shown consistent maintenance of the desired set points, operational testing to allow for "passive" periods can commence. It is highly likely that scheduled overnight shutdowns and even logic-based "off" periods – for example, if the space temperature and RH are within acceptable limits, and no call for conditioning (heating, cooling, dehumidification) has occurred for "X" time, the fan will shut down for a period of time until there is either a call for conditioning or a maximum time limit is hit, at which point the fan enables for circulation – could be successful in the Main Vault based on observation of low historic temperature and moisture loads in the space.

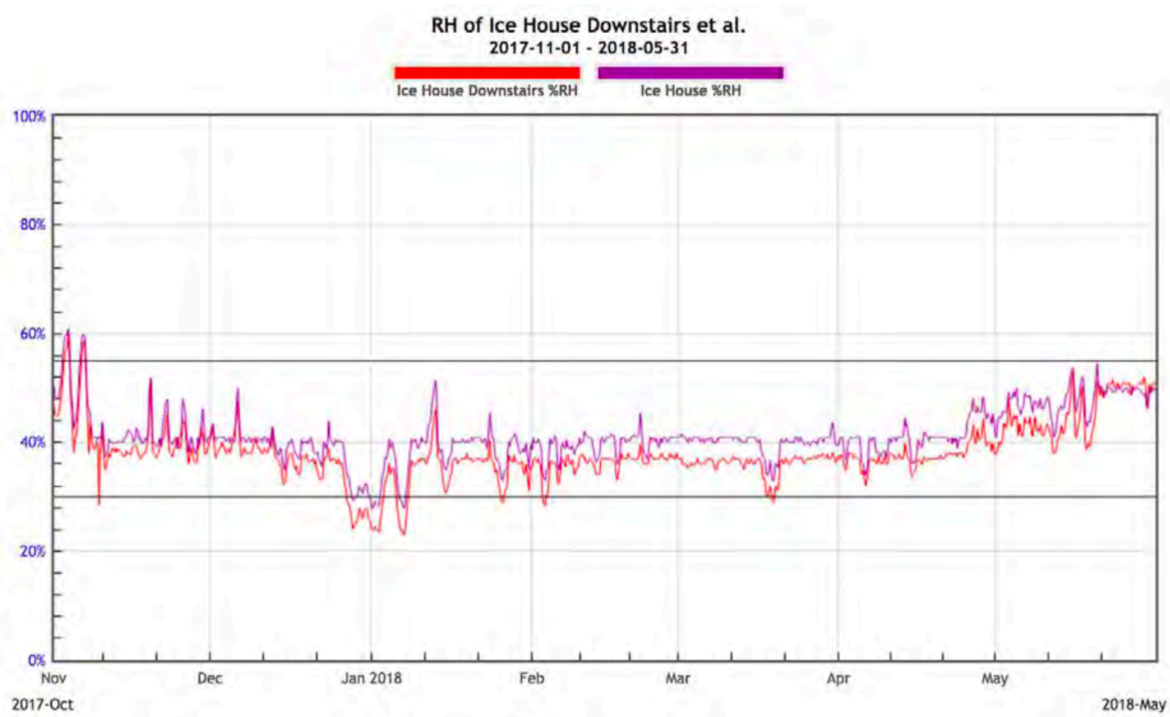
Ice House Vault

The Ice House Vault is covered by a total of six mechanical loggers – supply and return air for both the upper and lower floors, dehumidified air, and cooled air – as well as environmental dataloggers in each space. Environmental goals were:

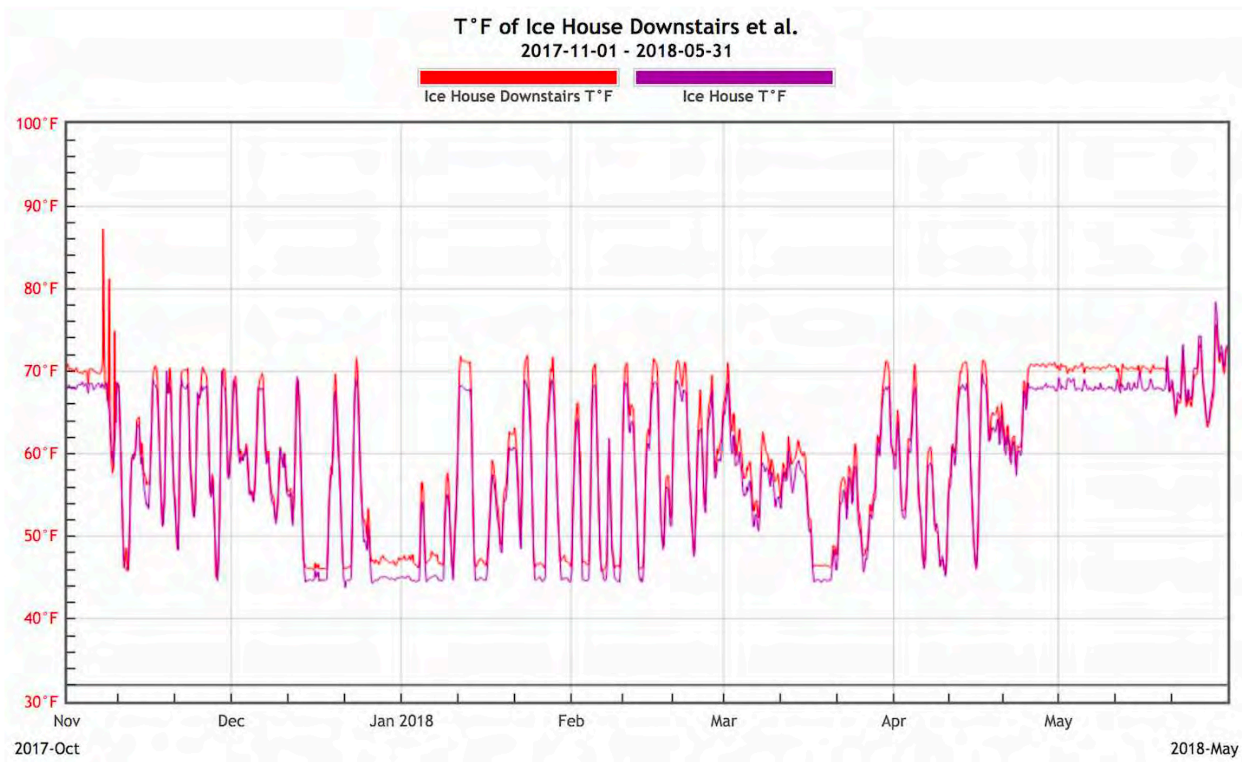
- Temperature: 70F summer max
  45F winter minimum (to protect oils and acrylics)
- RH: 55% summer max
  30% winter minimum (no humidification)

These conditions, if achieved, would combine reduced seasonal energy consumption with improved preservation over the course of the year – cool winter conditions bring down the overall rate of chemical decay, while the seasonal RH swings are kept within safe limits for the collections materials.

The programming for winter operation for the Ice House mechanical system is currently the same concept as the that in the Main Vault – humidistatic control based on achieving a specific space RH. Like the Main Vault, both floors of the Ice House show very steady RH conditions, with the lower floor (~36%) slightly lower than the upper floor condition (~40%). These RH differences are accompanied by corresponding differences in temperature operation. While neither RH condition is an issue from a preservation perspective, the team should check whether the difference between the floors is based on purposeful set point control, or if there is something else – control issue, sensor calibration, mechanical issue – influencing the performance. A difference in logger calibration is possible, but both loggers are showing the same dew point condition, which makes that possibility less likely. Like the Main Vault, the graphs show both the steady RH control as well as the regular fluctuation in temperature in order to control the RH.



Ice House, RH Graph - Winter 2017-2018. Note flatline control of RH condition.

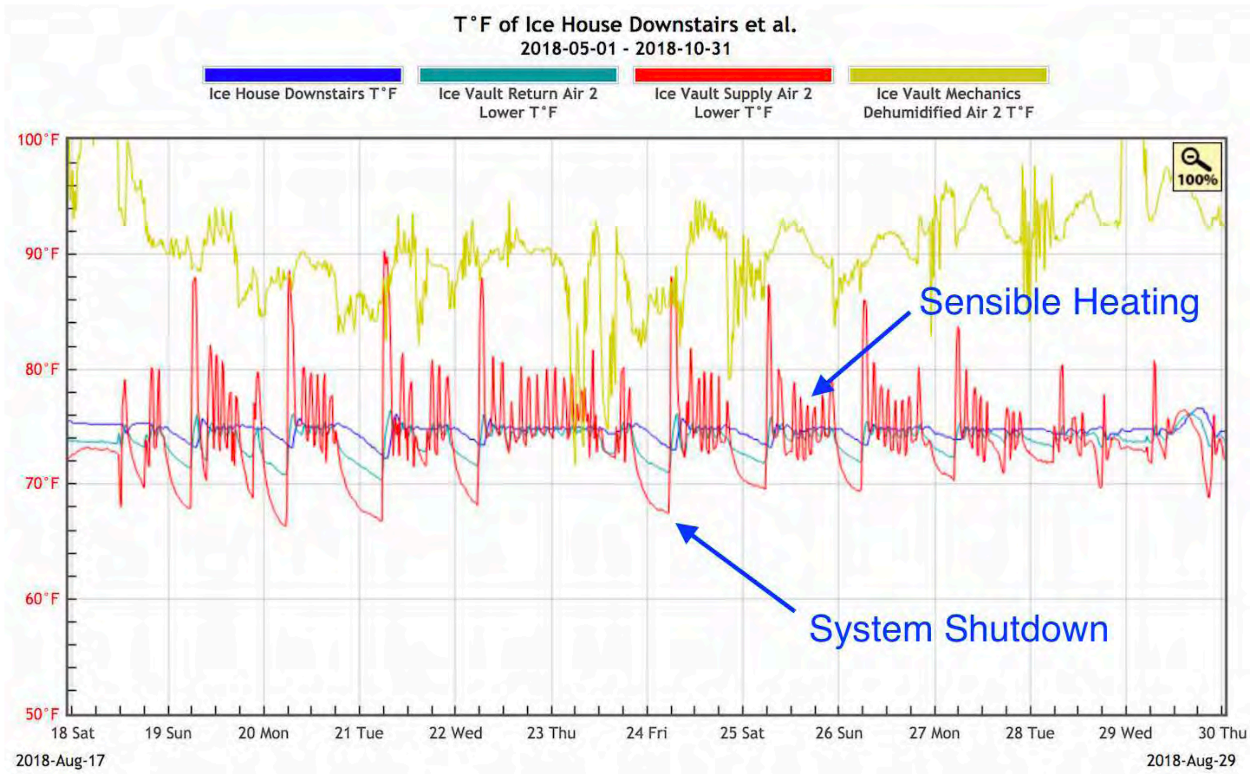


Ice House, T Graph - Winter 2017-2018. Note fluctuation in order to maintain the above flatline RH condition.

Like the Main Vault, the primary winter concern for the Ice House Vault is to keep the temperature condition as low as possible (45F minimum) while keeping the RH conditions within an acceptable band (the seasonal 30-55% range). These conditions have the dual benefits of slowing the rate of chemical decay through cooler winter space temperatures, decreasing energy costs by minimizing heating, while still maintaining a safe RH band for protecting against mechanical damage.

TWPI in the Ice House upper and lower floors was better than that of the Main Vault in winter 2017-2018 – both spaces ran showed a TWPI of 102-104 for the winter season, primarily due to less time spent at warmer temperatures. The winter preservation goal should be the same as the Main Vault – with control centered around allowing the space temperature to passive drop as low as 45F, TWPI conditions of 140 or better may be achievable for the winter season.

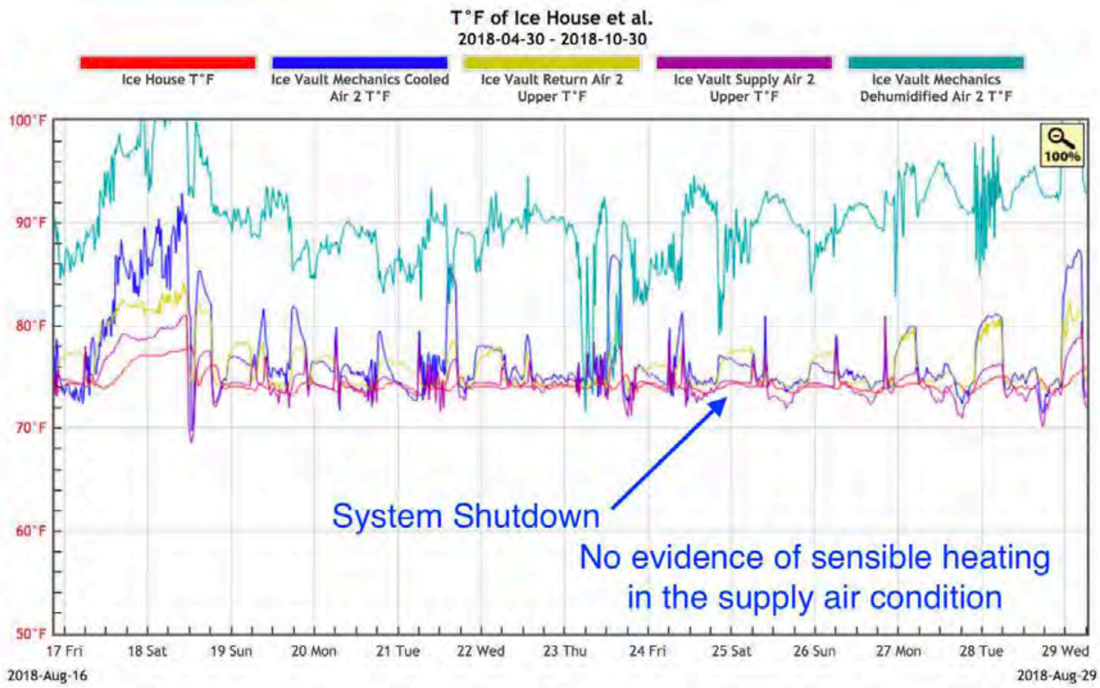
Both levels of the Ice House ran on an apparent 75F set point condition for the summer of 2018 which, like the Main Vault, should be lowered to a 70F set point if possible. Based on return air conditions and the impact of supply air on the space, temperature loads on the lower level appear to be minimal; the supply air shows a similar pattern to the Main Vault, appearing to actually be heating consistently through the summer. A span of operation in August 2018 seems to confirm this. For roughly ten days, the Ice House unit went through a series of nightly shutdowns (confirmed by readings from the electrical loggers) – each night during the shutdown, the space temperature dropped by ~2F. In addition to the shutdown, that same period also illustrates several surprises – supply air conditions fluctuate regularly, although not in relation to the dehumidification or the cooling temperature, which would indicate the unit was actually kicking into heating mode, potentially in response to a temperature drop below the set point temperature in the space. If that was the case, it does not appear to have been caused by over-operation of the cooling coil – the cooled air temperature is consistently similar to the space/return air temperatures, and does not appear to be overcooling.



Ice House, T Graph, 1st Floor - August 2018. Note the shutdown behavior and the sensible heating in order to maintain the space temperature set point.

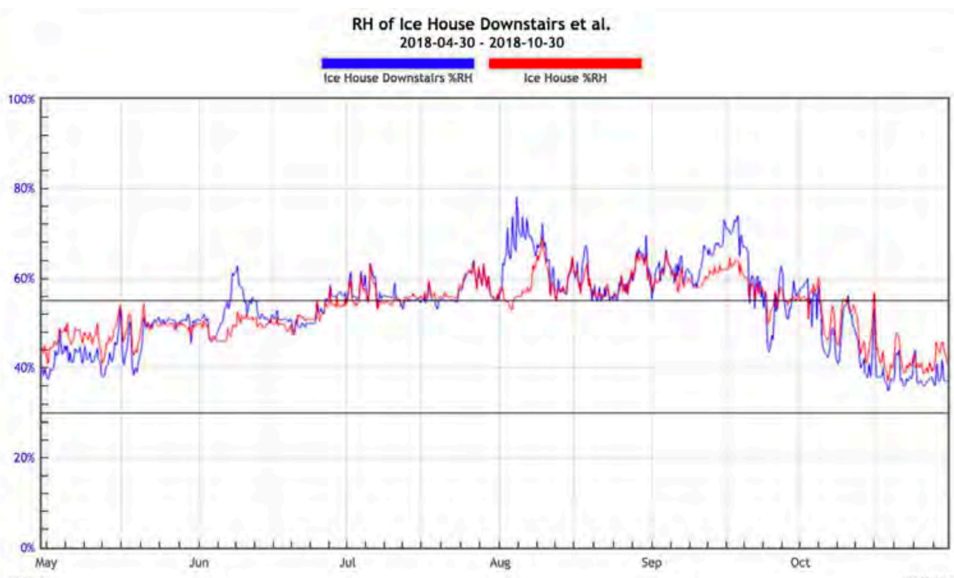
While the shutdowns appeared to be a short-lived event, the team should review available operational notes to determine whether this was a purposeful control, or if it was related to the power plant issues. Regardless of the cause, the data shows strong evidence that nightly shutdowns will be a viable strategy for energy-savings once the system control is finalized. The heating behavior never fully stopped, but is something that should be easily corrected by adjusting the logic that enables sensible heating.

A review of the data for the upper floor also shows the shutdown influence, although far more muted than the response of the first floor, raising the question of whether sub-floor temperatures may be influencing the first floor, or if heat gain from the roof may keep the second floor from cooling down. Interestingly, the second floor data shows no indication of the sensible heating behavior that the first floor did, indicating that the space was less-prone to cooling (likely due to roof loads).



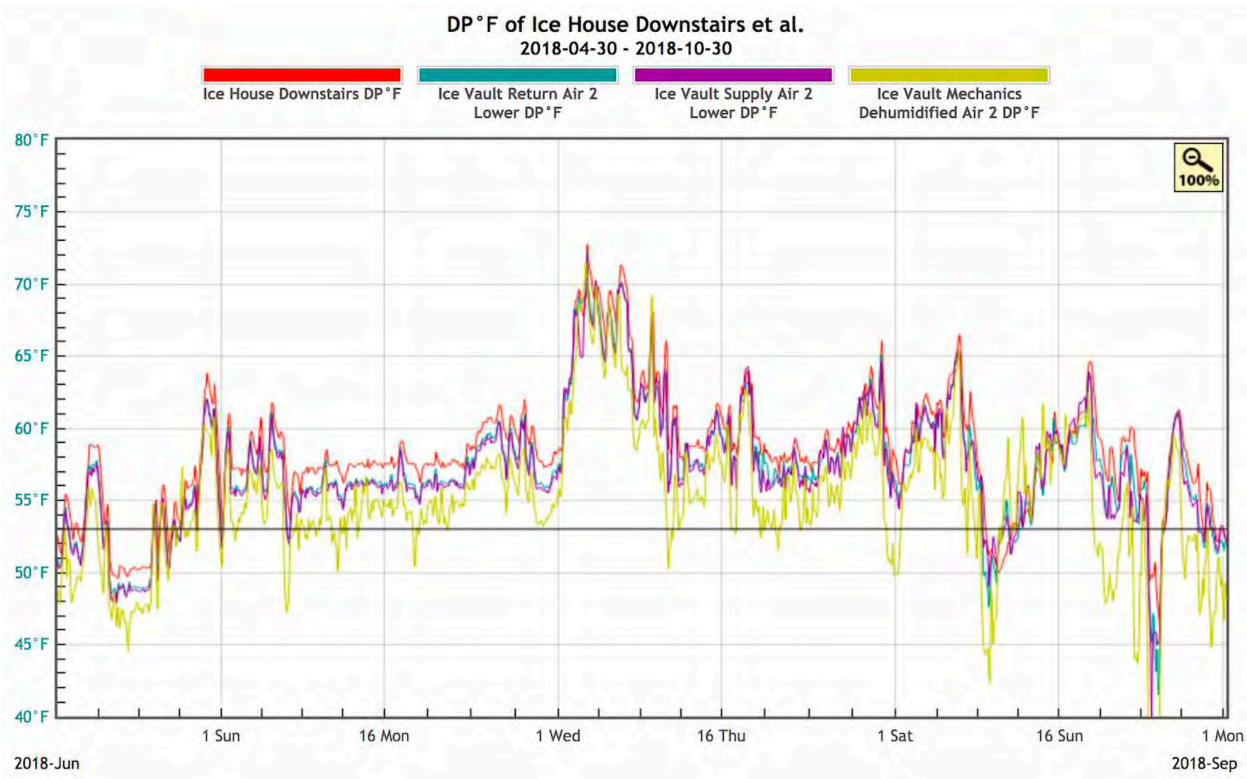
Ice House, T Graph, 2nd Floor - August 2018. Note the shutdown behavior (less impact on the space condition) and the lack of sensible heating compared to the 1st floor.

The Ice House Vault dehumidifier also fell somewhat short of its intended RH control during the summer of 2018. The goal condition, a maximum 55% RH, was briefly maintained in mid-July, but was high for the rest of the period, including several weeks where the lower floor was in the upper 60% ranges, with a potential for mechanical damage to some materials. Like the Main Vault, it is difficult to determine the precise cause of the lack of dehumidification, although the dew point graphs offer potential theories.



Ice House, RH Graph - Summer 2018. Limit lines are set to 30% and 55%, note RH conditions consistently above 55% for much of the summer.

Plotting the dew points of the various mechanical conditions shows that, as indicated in the temperature graphs, the dehumidifier is running, typically dropping the dew point of the process air by roughly 2F, which simply may not be enough to lower the space dew point sufficiently to maintain the RH condition. Of particular note is the fact that the dew point of the supply air condition is regularly identical to that of the return air condition. Assuming no issues with the data accuracy, this may indicate that either the dew point or the volume of the process air, compared to the return air, is not enough to significantly drop the overall dew point in the system.



Ice House, DP Graph - Summer 2018. Note that while the dehumidifier is running (yellow plot), the return and supply air dew points track the same.

Like the Main Vault, the summer RH conditions were not high enough to cause a threat for mold growth, although there was a small risk of mechanical shape change based on the higher RH and length of time at those conditions (particularly on the lower floor, which had not yet had collections in place for much of the summer), and a significant risk for oxidation of metallic elements in the storage environment. The warmer-than-desired temperatures, combined with higher RHs, slightly increased the overall rate of chemical decay compared to the design intent (summer design PI was 34, actual performance was a TWPI of 28/29).

<u>Ice House Recommendations</u>

Adjustments in control, further investigation into the operation (or lack of) of the dehumidifier, refinement of the heating operation, and improved cooling availability should allow the Ice House environment to fall within the environmental design targets. The following are suggestions for initial controls adjustments. Please note that these are broad guidelines based on past discussions of desired preservation and operational goals – the Monhegan staff and team should discuss final conditions and any limitations based on the installed mechanical and controls system. One important note is that while heating control can be isolated to the individual space sensors and the corresponding heating coils for each floor, the cooling and dehumidification control and equipment are shared for both floors. Based on data available so far, it is possible that the control sensors for these may need to be adjusted, with the humidistat on the lower floor controlling the dehumidification, and the thermostat on the upper floor controlling sensible cooling, due to load differentials. Control based on a blended return air condition is also an option, but will result in consistent differences on the two floors (likely with the lower floor being cooler and at a slightly higher RH than the upper floor) particularly if the goal is to avoid sensible heating in the summer months. From a set point and enabling perspective, the Ice House should mimic the Main Vault.

- Heating: can be enabled based on either of two conditions:
  - The space temperature drops below 45F. At that point, engage the heating until the space temperature reaches 50F. Heating shuts off until a call for heat at below 45F.
  - The space RH goes above 55%. At that point, engage the heating until the space RH reaches 50%. Heating shuts off until RH goes above 55% again. This action is only enabled when the chillers and dehumidifiers are offline (presuming that the chillers are taken offline for the winter).
- Cooling: is enabled based on one of the following two conditions:
  - The space temperature goes above 70F (adjustable), with or without dehumidification operation.
  - Whenever there is a call for dehumidification, cooling is enabled to sensibly cool the blended return/process air condition to the appropriate supply air condition (based on space temperature).
- Dehumidification: is enabled based on the following condition:
  - The space RH goes above 55%. At that point, dehumidification is enabled either to maintain 55% or until the space RH condition reaches 50% (or a lower selected condition). Dehumidification can be enabled at any temperature condition, provided that the chillers are online and available to sensibly cool the blended return/process air condition.
- Circulation/fan operation: is enabled "on" until consistent set point maintenance is achieved.

If successful, these set points and operations should result in a yearly band of temperature in the space between 45-70F – if the space temperature is within those ranges, no sensible temperature control should occur unless cooling is enabled for dehumidification. Likewise, the yearly RH band should stay below 55% and typically above 30% - though historical winter data is missing for the lower floor of the ice house, the winter 2017-2018 winter interior dew point conditions matched very closely to those of the Main Vault. If those low dew point conditions do not generally drop below 20F, at a 50F interior temperature (presuming that the low dew point condition will be accompanied by a cold outdoor temperature, and a call for heat) the space will still see a 30% RH.

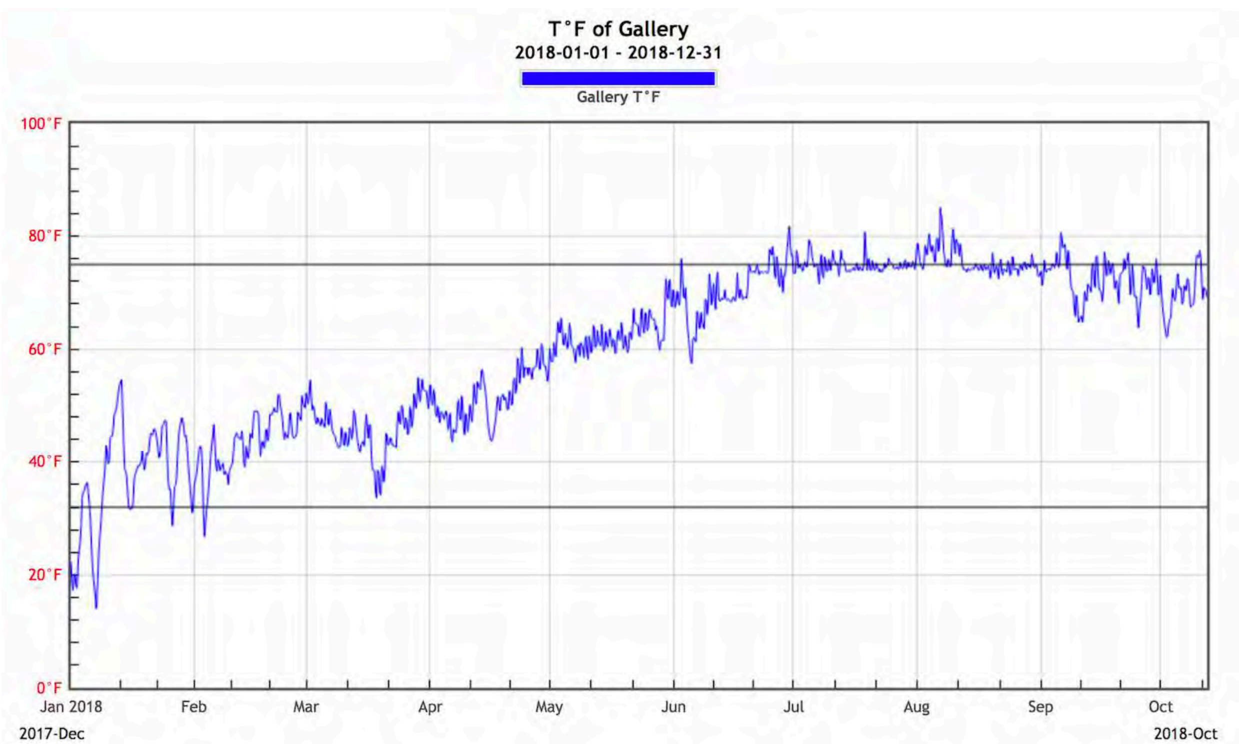
Note that these control adjustments do not account for unit scheduling (ie, shutdown testing) or setbacks in operation for the purpose of additional energy savings. Once the unit and controls have shown consistent maintenance of the desired set points, operational testing to allow for "passive" periods can commence. As the summer operation showed, it is highly like that scheduled overnight shutdowns and even logic-based "off" periods, like those described for the Main Vault, would be successful in the Ice House.

Gallery
The Gallery is monitored by a single environmental datalogger in the space, which has been in place since 2011. Without mechanical loggers in the system, analysis of actual operation is limited. Environmental goals discussed as part of the design parameters were:

- Temperature: 72F summer max for loan conditions
  No temperature control in winter.
- RH: 50% +/- 5% for summer loan conditions.
  55% summer max for all materials.
  No RH control in winter.

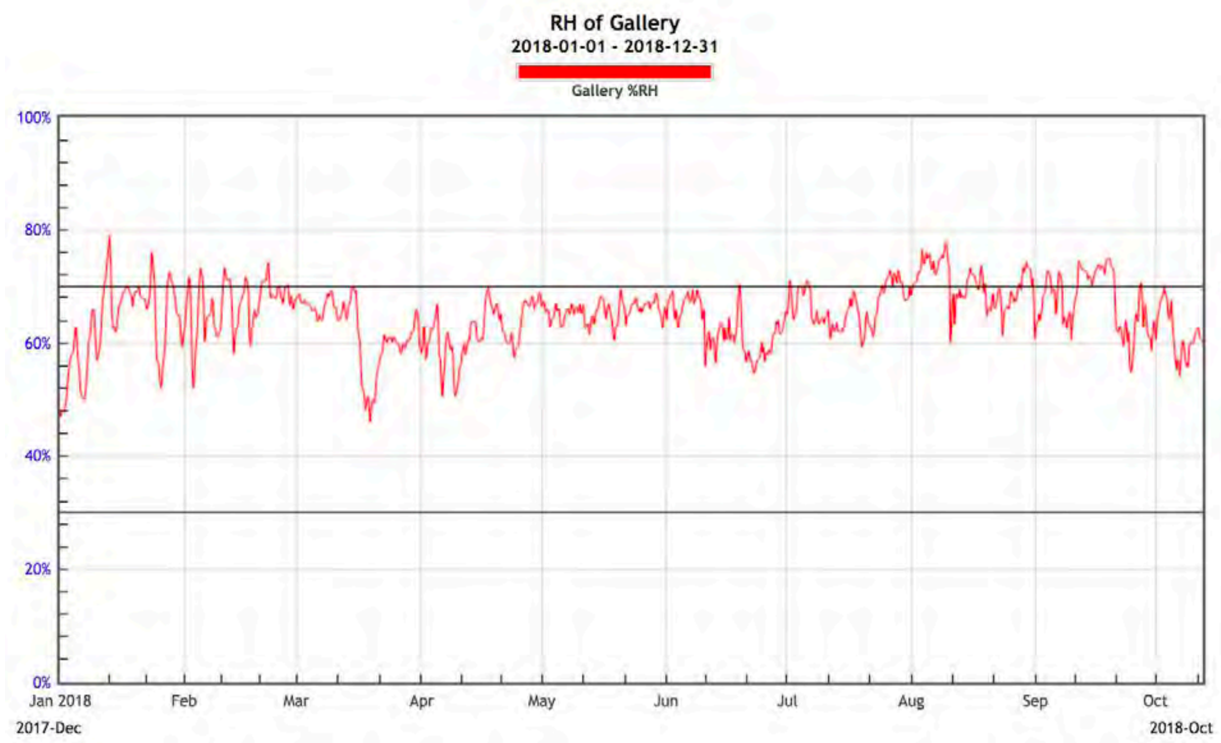
The primary concern for the Gallery environment is the ability to control RH during the summer season, when the yearly show is in various stages of set up, exhibition, and take down. In past years, without any available mechanical intervention, it was common for the RH in the Gallery to consistently remain above 70% RH, triggering a mold germination risk every summer, and making it difficult for the Museum to obtain loaned materials for exhibition from many potential lenders, particularly institutional partners.

The summer of 2018 was the first time the Gallery had received active mechanical intervention – though heat was available during the winter of 2017-2018, the decision was made to leave the space unheated in order to reduce energy costs. Temperature data from summer 2018 indicates that the system was generally successful in maintaining a 75F set point, with periods of warmer temperatures (up to 80F) that may correspond with periods when the chillers were offline.



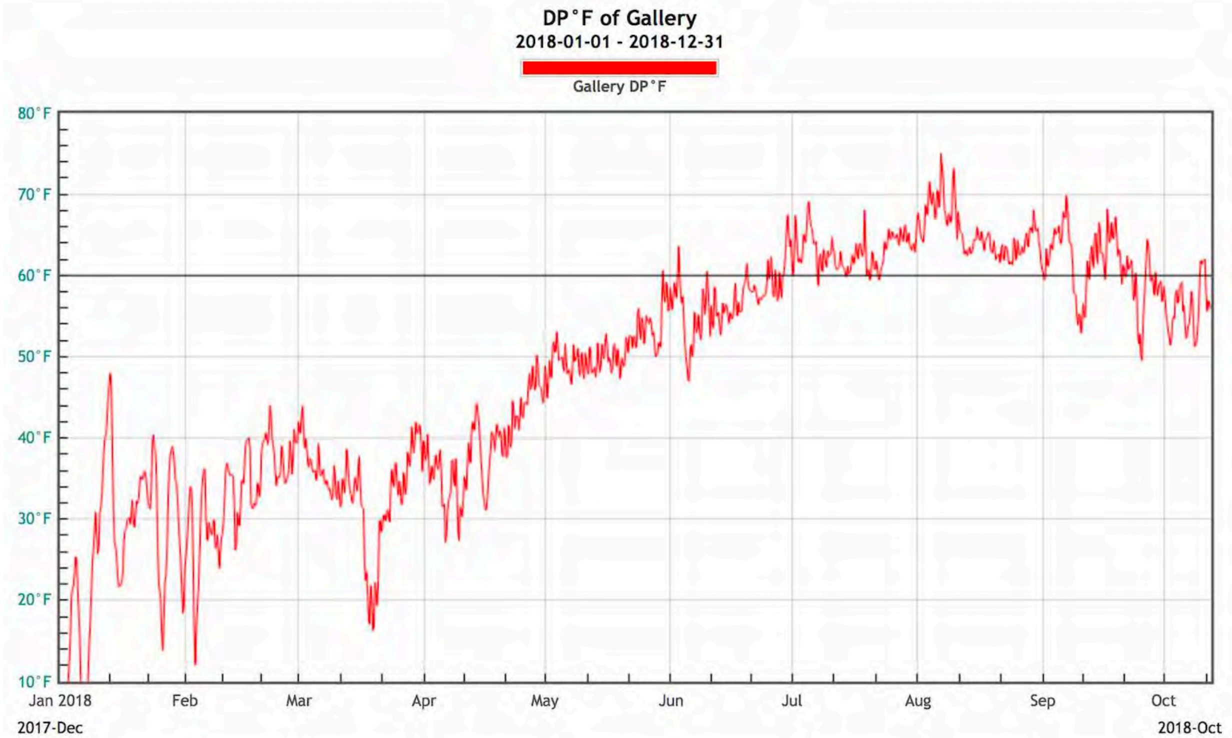
Gallery, T Graph - 2018. Limit lines are at 32F and 75F, note the unheated winter condition, and general set point maintenance in summer.

RH control, while better than in previous years, did not appear to meet any specific set point, with conditions regularly fluctuating between 60-70%, and creeping up above 70% in the late summer. Though the RH did not stay high enough for a long enough period to lead to likely mold germination, the environmental conditions still placed objects at risk of mechanical damage due to the consistently high RHs.



Gallery, RH Graph - 2018. Upper limit line is at 70% RH.

Without loggers in the mechanical system, it is difficult to specifically identify what the dehumidifier operation was; the pattern of the indoor dew point indicates that it is likely tracking fairly closely with outdoor conditions (there is no outdoor data available for this past summer to compare with). The originally discussed 72F/55% summer set points would have resulted in a 55F dew point; even if set points were raised to 75F/60%, the system should have maintained something close to a 60F dew point.



Gallery, DP Graph - 2018. The limit line is set at a 60F dew point, which would correspond to a 75F/60% RH condition.

The team discussed the challenges of maintaining the interior environment in the Gallery at length during the June site visit – past practice at the Museum has been to keep the main Gallery door open to invite visitors, and, even if kept closed, the team did not know what the impact of regular traffic would be. Based on the observed conditions, it would be worthwhile to review what practices the Museum adopted over the summer, and whether there are any opportunities to reduce loads, beyond resolving the operation of the dehumidifier itself.

<u>Gallery Recommendations</u>

The operation of the Gallery interior environment was carefully discussed during the onsite visit, with the dual goals of providing trim conditioning to mitigate the worst of the risk conditions, while also minimizing the overall energy consumption, especially since this is a newly conditioned space that was not necessarily designed with interior control in mind. The working presumption is that the space will remain unconditioned during the offseason, although staff may wish to extend the conditioned period depending on how long artwork must remain in the space after the Gallery closure. Ideally, two alternate summer control conditions would be available: one for when the only materials on display are part of the Museum collection, and can be maintained at broader – yet still safe – set point ranges, and one for when loaned materials are on display, and particular environmental conditions are specified as part of the loan agreement. The following are suggestions for initial controls adjustments:

- Heating: disabled. If collection items are kept in the Gallery into the winter season (photography projects or temporary storage being examples), the Gallery heat could run on similar operational guidelines as the Main Vault and Ice House:
    - The space temperature drops below 45F. At that point, engage the heating until the space temperature reaches 50F. Heating shuts off until a call for heat at below 45F.

- The space RH goes above 55%. At that point, engage the heating until the space RH reaches 50%. Heating shuts off until RH goes above 55% again. This action is only enabled when the chillers and dehumidifiers are offline (presuming that the chillers are taken offline for the winter).

- Cooling: is enabled based on one of the following conditions:
  - (Non-Loan Exhibits) Cooling is enabled when the space temperature goes above 75F (adjustable), with or without dehumidification operation.
  - (Loan Exhibits) Cooling is enabled when the space temperature goes above 72F (adjustable) with or without dehumidification operation.
  - Whenever there is a call for dehumidification, cooling is enabled to sensibly cool the blended return/process air condition to the appropriate supply air condition (based on space temperature).
- Dehumidification: is enabled based on the following condition:
  - (Non-Loan Exhibits) The space RH goes above 60%. At that point, dehumidification is enabled either to maintain 60% or until the space RH condition reaches 55% (or a lower selected condition).
  - (Loan Exhibits) The space RH goes above 55%. At that point, dehumidification is enabled either to maintain 55% or until the space RH condition reaches 50% (or a lower selected condition).
  - Dehumidification can be enabled at any temperature condition, provided that the chillers are online and available to sensibly cool the blended return/process air condition.
- Circulation/fan operation: is enabled "on" until consistent set point maintenance is achieved.

If successful, the two control options/set point sets should result in:

Non-Loan Exhibits:	75F max
	60% RH max
Loan Exhibits:	72F max
	55% max

The goal for testing would be to start with the lower set point conditions – 72F/55% – and confirm the system capability at those conditions for 2-3 weeks during summer conditions, and to test the 75F/60% RH environment for 2-3 weeks.

Discussion with Monhegan staff indicated the desire to eventually test occupied versus unoccupied modes for Non-Loan Exhibits as a means of hopefully utilizing short-term fluctuations based on system shutdowns or set point setbacks as a means of increased energy-savings. With limited data, it is hard to say how the Gallery space might respond the tests, which should only be conducted once the system has shown consistent performance in maintaining the desired set point conditions.

Office/Archives

Like the Gallery, the Office/Archives is monitored by a single environmental datalogger in the space, which has been in place since 2011. Without mechanical loggers in the system, analysis of actual operation is limited. Environmental goals discussed as part of the design parameters were:

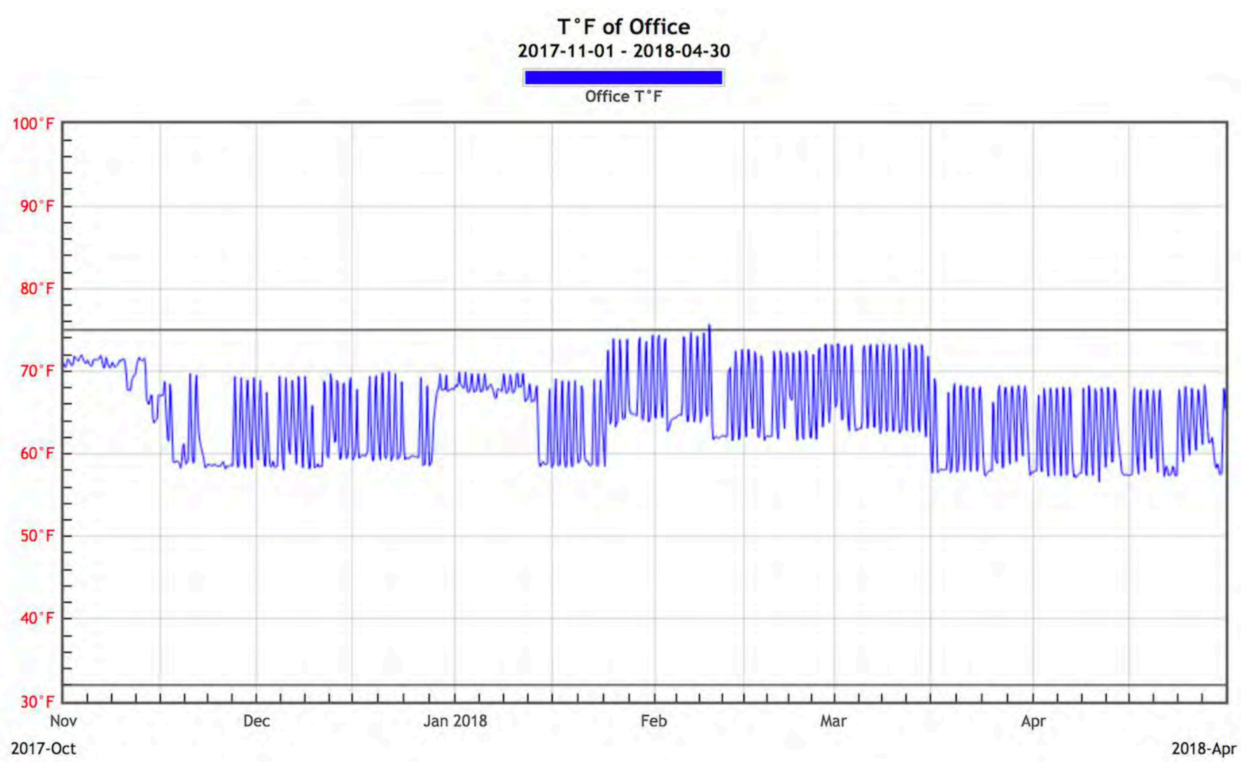
- Temperature: 72F summer max
  68-70F winter max (when occupied)
  55-60F winter minimum (to allow recovery of heat for comfort)

- RH: 55% summer max
  Variable winter RH (no humidification)

The goal of the Office environment is to provide appropriate preservation conditions for the archival collections that will continue to be held in the space while at the same time allowing for a human comfort environment. By setting maximum summer temperature conditions and allowing the temperature to drift cooler during unoccupied winter periods, the Museum can achieve a balance between an acceptable preservation environment and limited energy usage. Working to keep the RH below 55% accomplishes the same goal – managing dehumidification levels while keep RH conditions low enough to protect materials such as black and white photographs from silver oxidation.

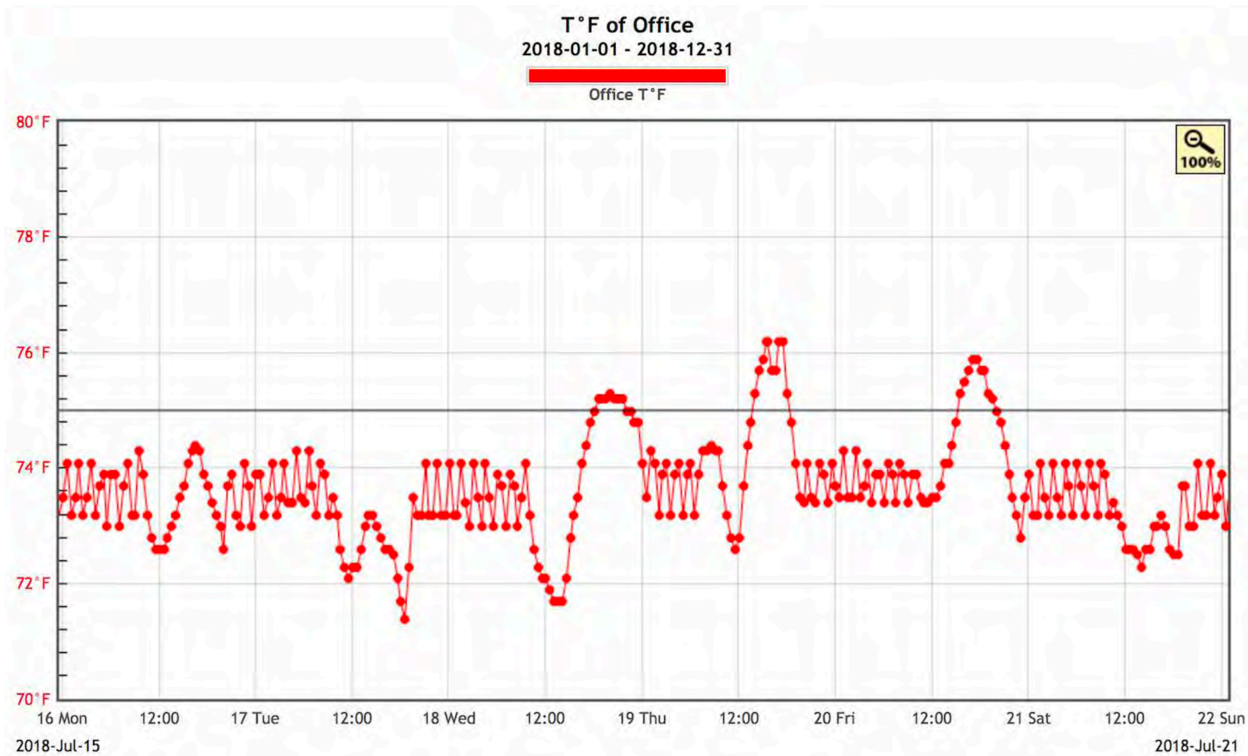
Temperature in the space historically has ranged between 60-75F throughout the year, with occasional periods outside those conditions. Summer RH conditions have typically been between 60-70% – shy of mold growth concerns, but potentially problematic from a mechanical perspective and, combined with warm temperatures, less than ideal for rates of chemical decay.

The winter of 2017-2018 was the first winter on the new systems, with the old propane heaters removed. The temperature plot and pattern of operation seem very close to the final desired conditions, with occupied temperatures between 68-72F (there was a set point change from 72-68F midseason), and unoccupied conditions between 58-62F. While active heating was provided during occupied hours, the temperature was allowed to drift cooler during unoccupied hours until it hit the low-limit temperature, where it maintained until the occupied mode kicked in. RH, which is not part of the winter control, typically ranged between 20-40%, spending roughly a quarter of the season below 30%.



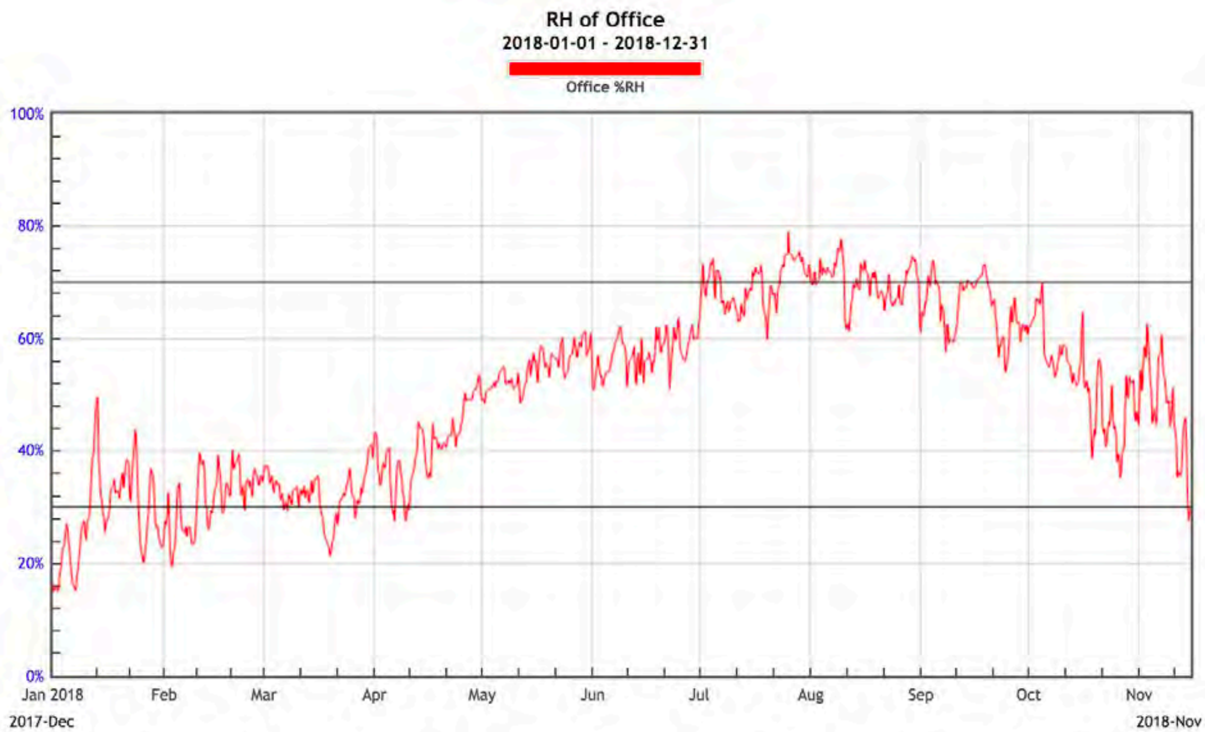
Office, T Graph - Winter 2017-2018. Note daily occupied/unoccupied control with weekends. Warmer temperatures in early January were in response to cold outdoor conditions.

Summer operation was largely successful in keeping the temperature below 75F, with the spike in early August 2018 likely attributable to the power plant issues and chiller unavailability. One concern is that the summer temperature pattern in the office shows a regular sawtooth throughout the day – while this behavior is common in DX/refrigerant based systems, in a chilled water application it may indicate alternating behavior between cooling and heating. Without mechanical data it is difficult to say what the actual behavior was, but the team should review the current control and look for potential causes. While the overall control generally meets the environmental requirements, if the unit is regularly heating to maintain the condition, it will increase the overall energy expenditure.

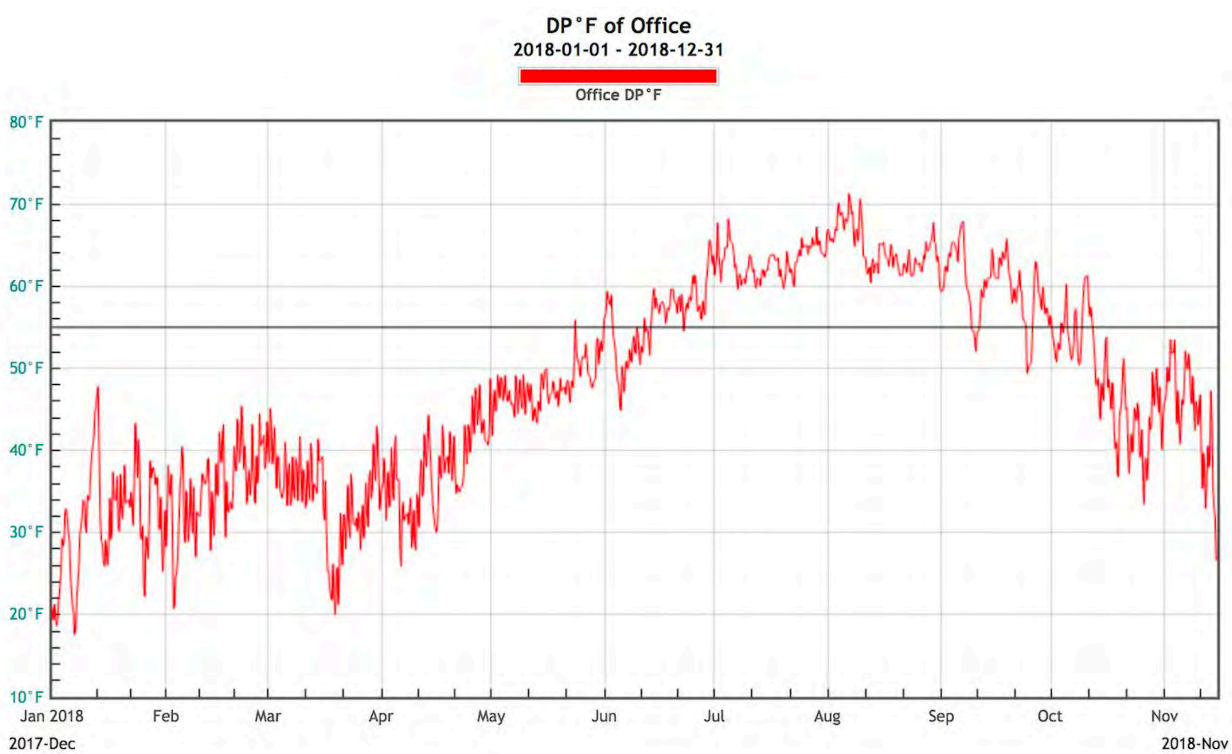


Office, T Graph - Summer 2018. Sawtooth pattern may indicate alternating behavior between cooling and heating.

RH control exhibited the same operational issues as the Gallery and the Vaults, with no discernible set point maintenance and a dew point that appeared to fluctuate in rapidly in response to outdoor conditions. Like the Office, the presumption is that the dehumidifier was actively running throughout the summer. By mid-summer, RH conditions were regularly exceeding 70%, although not for periods long enough to encourage mold germination. These conditions create a risk for both mechanical damage as well as silver oxidation in the photograph collections.



Office, RH Graph - 2018. Summer conditions rarely drop below 60% RH with regular operation above 70%.



Office, DP Graph - 2018. The limit-line indicates the likely interior dew point at a 72F/55% environment.

Office/Archives Recommendations

The operation of the Office/Archives interior environment was carefully discussed during the onsite visit in an effort to determine best-case operation for both preservation and occupancy. In winter, the goal is to minimize heating while still being able to maintain human comfort for the occupied hours – staff suggested a 70F occupancy set point that would be allowed to drift at low as 60F during unoccupied periods. For summer conditions, the maximum temperature would be set at 75F (cooler is acceptable – the goal is not to heat during the summer season) while allowing temperature to drift cooler overnight. RH control should be set to a maximum 55% condition throughout the summer. The following are suggestions for initial controls adjustments:

- Heating: can be enabled based on either of two conditions:
    - Occupied: The space temperature drops below 70F during the winter season. Unless directed otherwise by Museum staff, heating should not engage during occupied periods in summer operation.
    - Unoccupied: The space temperature drops below 60F (year-round).
    - It is expected that Museum staff may engage heating for short periods based on day-to-day conditions (such as a cool spring or fall day), even during the summer period. If possible, there should be a means of achieving this for temporary operation without altering the actual programmed control.
- Cooling: is enabled based on one of the following two conditions:
    - The space temperature goes above 75F (adjustable), with or without dehumidification operation.
    - Whenever there is a call for dehumidification, cooling is enabled to sensibly cool the blended return/process air condition to the appropriate supply air condition (based on space temperature).
- Dehumidification: is enabled based on the following condition:
    - The space RH goes above 55%. At that point, dehumidification is enabled either to maintain 55% or until the space RH condition reaches 50% (or a lower selected condition). Dehumidification can be enabled at any temperature condition, provided that the chillers are online and available to sensibly cool the blended return/process air condition.
- Circulation/fan operation: is enabled "on" until consistent set point maintenance is achieved.

If successful, the two control this operation should provide for:

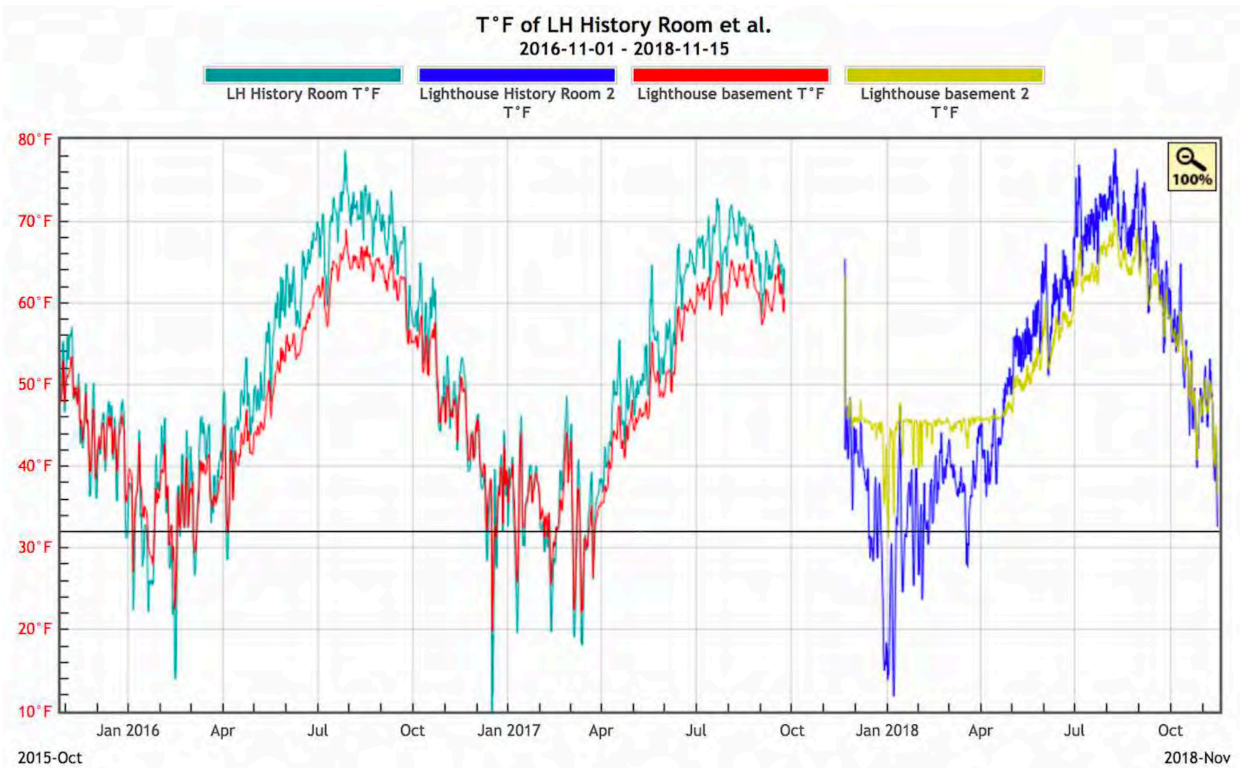
Occupied:	70F max
	55% RH max (summer)
Unoccupied:	60F minimum
	55% max (summer)

Scheduling of the occupancy schedule should be finalized with Museum staff, but general guidelines may be:

Heat enable (if no previous call):	7AM
Working hours:	9AM-4PM
Passive drift to cool limit:	4PM-7AM

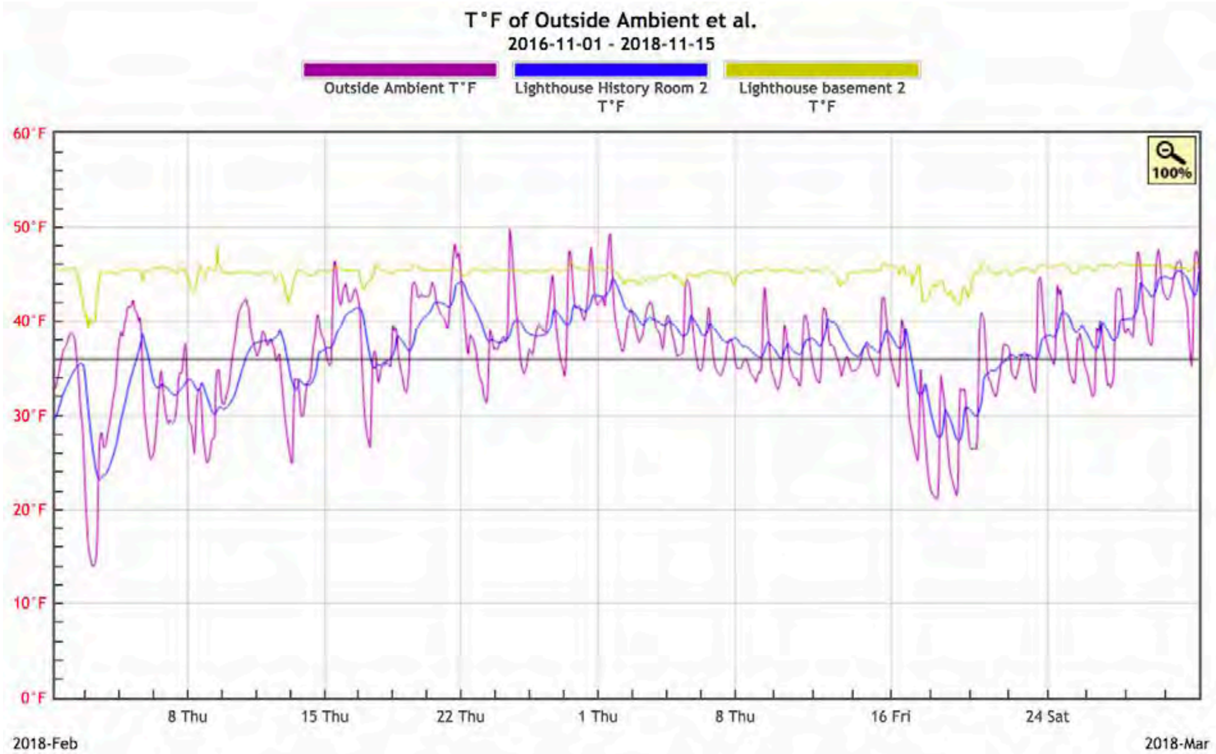
Keeper's House
The Keeper's House is monitored in five exhibit locations as well as in the attic and the basement. As mentioned above, the primary action for the historic structure was period-appropriate repair; the availability of the heat recovery inspired the team to consider low-level basement heat as a potential aid in mold prevention. With the addition of hanging fin-tube in the basement area, the only operational goal was to slightly warm the basement space during the winter months in order to reduce RH both in the basement, and hopefully, the first floor. For the winter of 2017-2018, the heat recovery in the basement ran to maintain a temperature of 45F.

The impact on the basement temperature over the winter months is clear – basement temperatures (red and yellow plots below) have traditionally run between 30-40F, with significant time spent below freezing each winter. In 2017-2018, the basement temperature stayed consistently above 40F, with the exception of the cold front over the new year period.



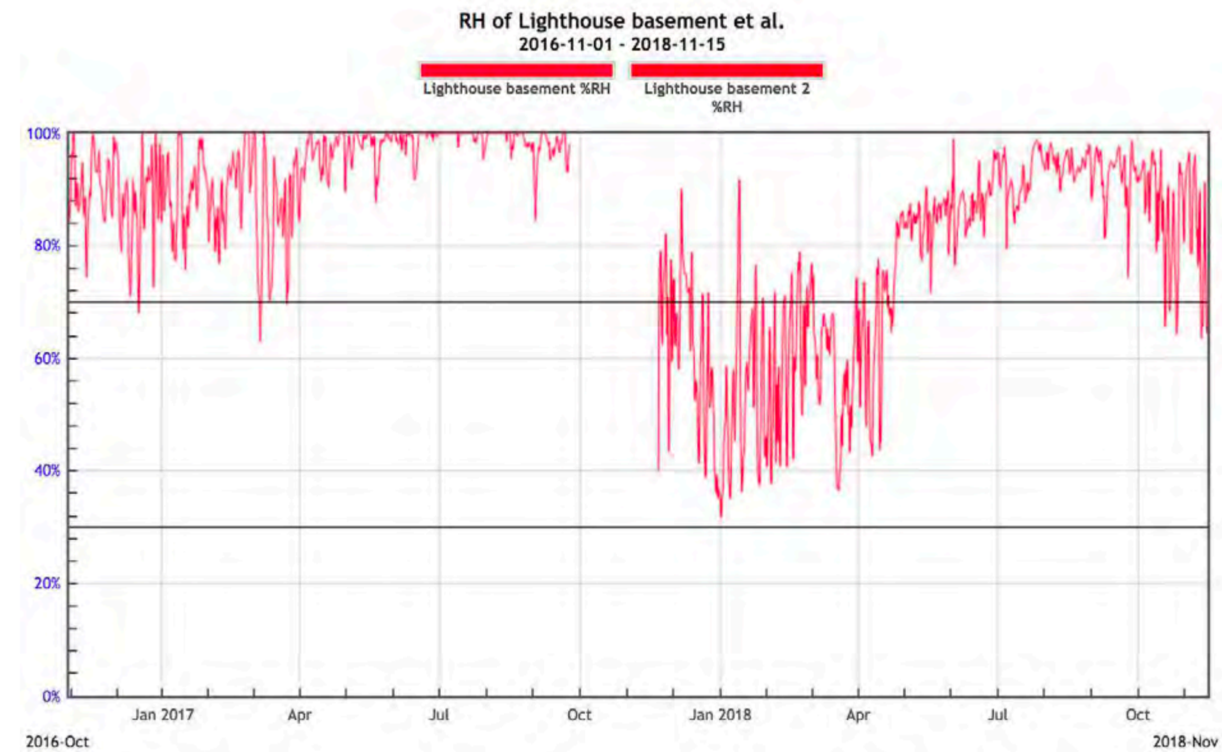
Keeper's House, Basement T - 2015-2018. Basement conditions are red/yellow plots, teal/blue plots are for the History Room.

The impact on the floor above – the History Room area, is less clear. The first-floor temperature trends consistently higher in February-March 2018 than it did in years past, but it is difficult to tell how much is the influence of exterior conditions, and how much may be the basement heat. An overlay of the available outdoor data shows that the History Room temperature in February-March 2018 was much more muted in response to outdoor temperature swings that it had been in years past. Previous years showed the History Room responding quickly to outdoor conditions, with temperatures indoor nearly as cold (or warm) as those outdoors. The influence of the heat seems to have kept the History Room anywhere from 3-10F warmer than outdoor conditions, which was new behavior compared to the winters of 2016 and 2017.

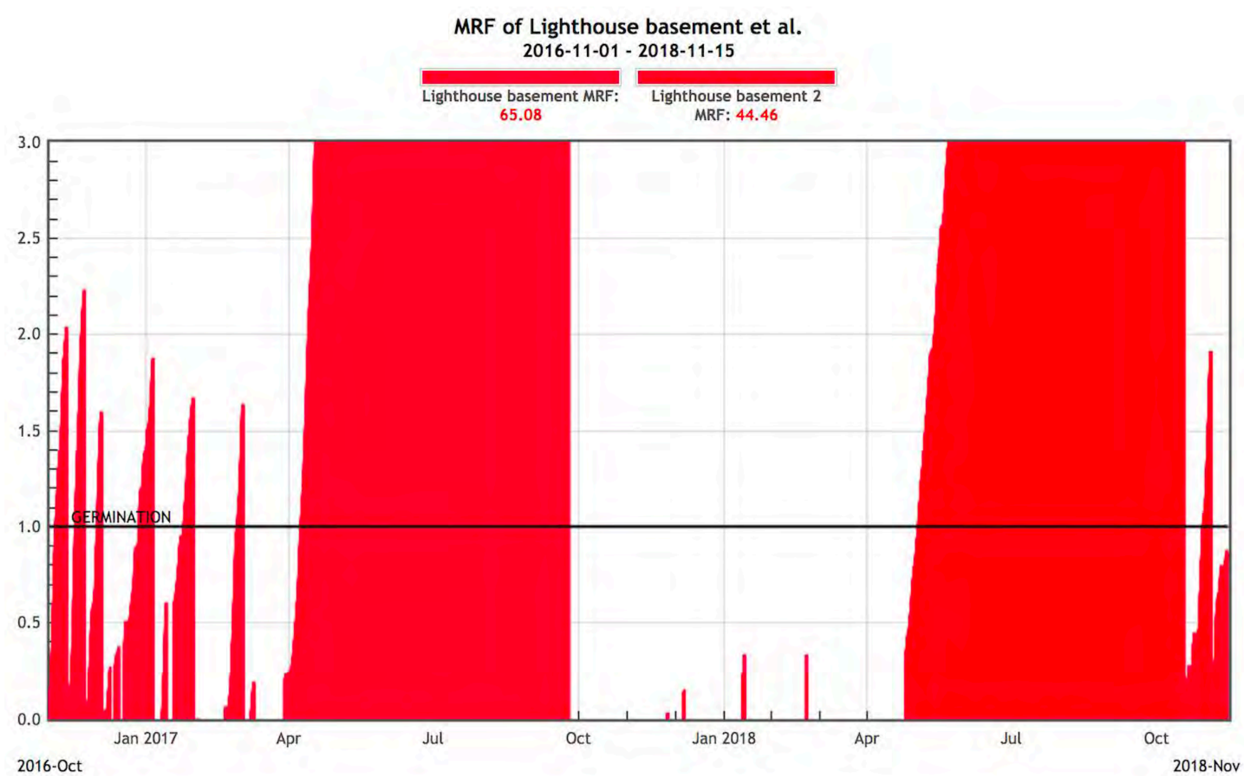


Keeper's House, T Graph - Winter 2018. Note the muted behavior of the History Room temperature (blue plot) compared to the outdoor air condition (purple).

In various conversations over the period of the project staff noted that the cleaning mold off of the walls of the Keeper's House, particularly in the several of the first-floor rooms, was a typical task each spring. The impact of heating the basement is clear in the basement RH graph – RHs drop from conditions between 80-100% in the winter of 2016-2017 to only occasionally going above 70% in the winter of 2017-2018 (see below graph). This had a significant impact on the risk of mold growth in the basement – conditions went from regular risk of germination in winter 2016-2017, to no risk at all in 2017-2018. While there are still issues with high RH and potential mold growth during the summer months, the addition of heat in the winter effectively lowered RH and mold risk in the basement area.

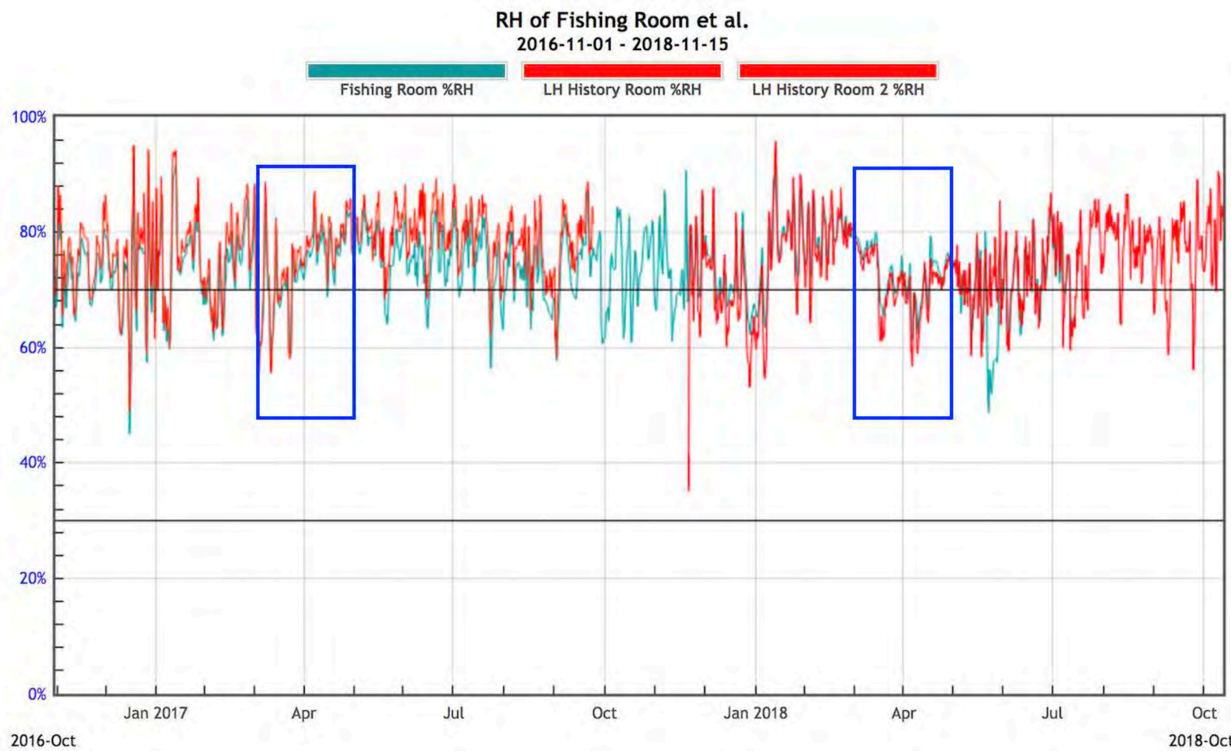


Keeper's House, Basement RH Graph - 2016-2018. Note the low RH in winter 2017-2018 compared to the previous year.



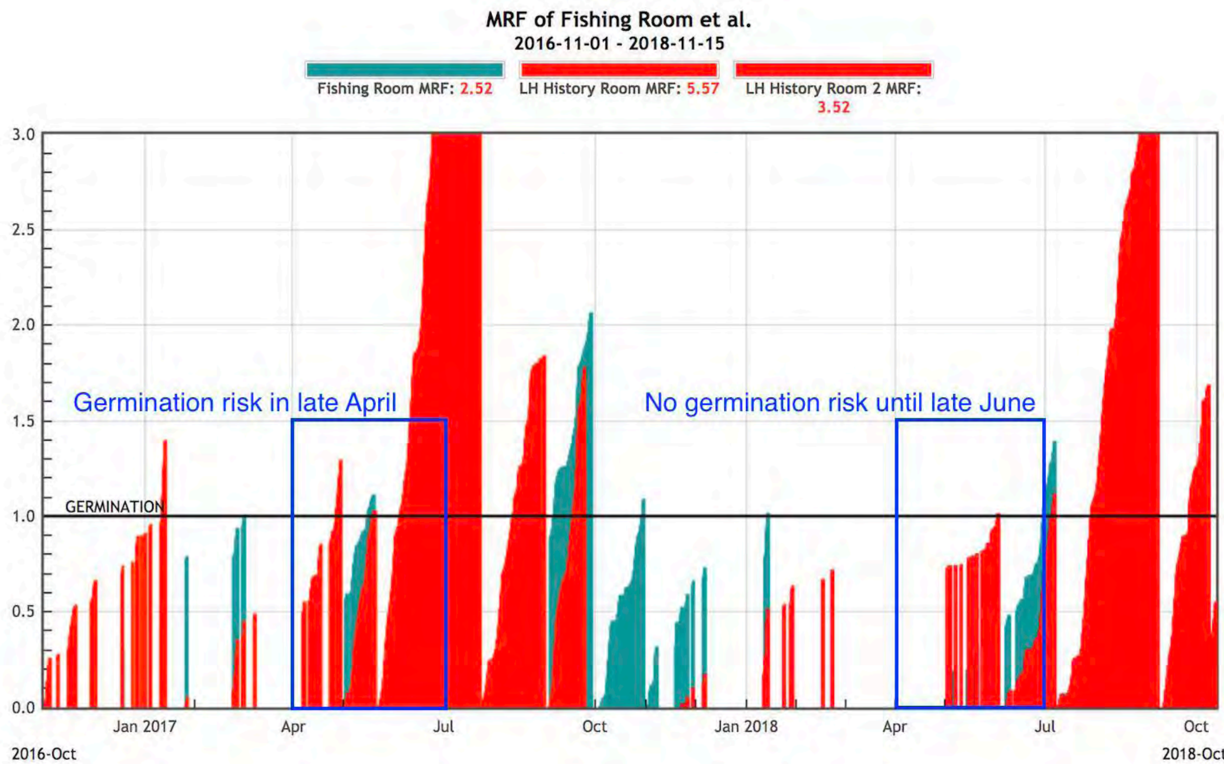
Keeper's House, Basement Mold Risk Factor (MRF) - 2016-2018. Note no mold risk factor in winter 2017-2018 compared to the previous year.

RH on the first floor History and Fishing Rooms did not respond as drastically – comparing months in winter 2016-2017 to those in 2017-2018, RH conditions are generally lower in November-December 2017, but the January-February 2018 conditions appear quite similar to the previous year. The key to the lack of mold growth in spring 2018 appears to lie in the March-April 2018 conditions, which are noticeably lower than those the previous year.



Keeper's House, First Floor RH Graph - 2016-2018. In the outlined boxes, note the lower RH conditions in 2018 compared to 2017.

Though there are multiple variables that could have caused the lower RH condition, many of the structural improvements had been completed prior to the winter of 2016-2017, with the additional of the basement heat being the key difference between the two data periods. While the difference is clear, the 2018 RH still does not seem quite low enough to limit mold germination – conditions are still regularly above 70% RH, and were previously high for much of January and February. Inspection of the Mold Risk Factor graph and algorithm reinforce the lack of visible mold growth in spring 2018 – even though RH conditions still seem high, the MRF is sufficiently below germination points for the entire winter of 2017-2018, and do not reach risk levels until late June 2018. Though the Museum should continue to document any observed mold each spring as well as review environmental data for indications of risk, the available data thus far indicates that the decision to add minimal heat to the Keeper's House basement likely played a large part in limited mold growth on the first floor of the house in Spring 2018.



Keeper's House, First Floor MRF Graph - 2016-2018. Germination risk in spring 2018 is significantly less than in 2017.

<u>Keeper's House Recommendations</u>

The Museum should continue to provide minimal heat (set point of 45F – similar to winter 2017-2018) to the Keeper's House basement as a means of limiting the risk of winter/spring mold germination in both the basement and the first floor of the House. Yearly physical inspection should continue for mold germination; data should be reviewed and analyzed again in spring 2019 to determine whether the patterns shown thus far remain consistent.

MUSEUM HVAC SYSTEMS & EQUIPMENT MAINTENANCE PLAN (Year 20____)

Area / System	Item	Task	Frequency	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Performed By	Completion Date(s)	Work Order #
Chilled Water	Chiller ACCH-1 (See Manual for additional info)	Check refrigeration charge	Annual															
		Inspect condenser coil for cleanliness (clean if dirty)	Annual															
		Cycle chiller to verify operation	Annual															
	Chiller ACCH-2 (See Manual for additional info)	Check refrigeration charge	Annual															
		Inspect condenser coil for cleanliness (clean if dirty)	Annual															
		Cycle chiller to verify operation	Annual															
	Glycol Feed Tank	Check system glycol pressure & fill tank reserve	Annual															
	Chilled Water Loop (Glycol 40%)	Test glycol level (% by Vol), pressure and for quality/acidity	Annual															
		Inspect system/piping/fittings for glycol leaks	Annual															
		Verify operation of relief valve	Annual															
		Verify all air has been purged & vents are functioning	Annual															
	Pump CHWP-1	Verify pump operation is normal & clean strainer.	Annual															
	Pump CHWP-2	Verify pump operation is normal & clean strainer.	Annual															
	Bypass valve	Verify end-of-line mechanical bypass is functioning	Annual															
	Expansion Tank	Verify 12 psi air charge on diaphragm	Annual															
Hot Water	Boiler B-1 (See IOM and Service Manual for additional info)	Check for diagnostic alarm history and note recurring issues	Annual															
		Check for gas leaks	Annual															
		Verify condensate trap is full	Annual															
		Perform Owner & maint procedures in Service Man (Chapter 2)	Annual															
		Perform start-up procedure in IOM (Chapter 10)	Annual															
	Gas Supply (next to Ice House)	Verify propane tank levels and delivery pressures	Annual															
	Hot Water Loop (Glycol by MPPD)	Test glycol level (% by Vol), pressure and for quality/acidity & inform MPPD	Annual															
		Inspect system/piping/fittings for glycol leaks	Annual															
		Verify all air has been purged & vents are functioning	Annual															
	Pump HWP-1	Verify pump operation is normal & clean strainer.	Annual															
	Pump HWP-2	Verify pump operation is normal & clean strainer.	Annual															
	Pump BP-1	Verify pump operation is normal & clean strainer.	Annual															
	Bypass valve	Verify end-of-line mechanical bypass is functioning	Annual															
	Expansion Tank	Verify 12 psi air charge on diaphragm	Annual															
Solar System	Pump EP-1	Verify pump operation is normal & clean strainer.	Annual															
	Solar Thermal Loop (Glycol 40%)	Test glycol level (% by Vol), pressure and for quality/acidity	Annual															
		Inspect system/piping/fittings for glycol leaks	Annual															
		Verify operation of relief valve	Annual															
		Verify all air has been purged & vents are functioning	Annual															
	Expansion Tank	Verify air charge on diaphragm ~ max of fill tank pump	Annual															
	Solar Collectors (4 total)	Check condition and cleanliness of tubes	Annual															
		Check mounts and hardware for integrity	Annual															
		Verify heat dissipators are free and clear (not plugged/dirty)	Annual															
Gallery	AHU-G	Check Filters (in Separate Filter Unit Only)	Quarterly															
		Check condensate pan & drain	Annual															
		Check unit interior for cleanliness	Annual															
		Verify operation of fan	Annual															
		Inspect CHW coil for cleanliness (clean if dirty)	Annual															
	DH-G	Check cleanliness of wheel (vacuum if dirty)	Annual															
		Verify rotation of wheel	Annual															
		Verify operation of both fans	Annual															
		Inspect HW coil for cleanliness (clean if dirty)	Annual															
		Check collar connections of any flex ducts for integrity	Annual															
Office	AHU-O	Check Filters (in Separate Filter Unit Only)	Quarterly															
		Check condensate pan & drain	Annual															
		Check unit interior for cleanliness	Annual															
		Verify operation of fan	Annual															
		Inspect CHW coil for cleanliness (clean if dirty)	Annual															
	DH-O	Check cleanliness of wheel (vacuum if dirty)	Annual															
		Verify rotation of wheel	Annual															
		Verify operation of both fans	Annual															
		Inspect HW coil for cleanliness (clean if dirty)	Annual															
		Check collar connections of any flex ducts for integrity	Annual															
Vault	FCU-V	Check Filters (in Separate Filter Unit Only)	Quarterly															
		Check condensate pan & drain	Annual															
		Check unit interior for cleanliness	Annual															
		Verify operation of fan	Annual															
		Inspect CHW coil for cleanliness (clean if dirty)	Annual															
		Check cleanliness of wheel (vacuum if dirty)	Annual															
		Verify rotation of wheel	Annual															

MUSEUM HVAC SYSTEMS & EQUIPMENT MAINTENANCE PLAN (Year 20____)																		
Area / System	Item	Task	Frequency	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Performed By	Completion Date(s)	Work Order #
	DH-V	Verify operation of both fans	Annual															
		Inspect HW coil for cleanliness (clean if dirty)	Annual															
		Check collar connections of any flex ducts for integrity	Annual															
Ice House	FCU-IH	Check Filters (in Separate Filter Unit Only)	Quarterly															
		Check condensate pan & drain	Annual															
		Check unit interior for cleanliness	Annual															
		Verify operation of fan	Annual															
		Inspect CHW coil for cleanliness (clean if dirty)	Annual															
	DH-IH	Check cleanliness of wheel (vacuum if dirty)	Annual															
		Verify rotation of wheel	Annual															
		Verify operation of both fans	Annual															
		Inspect HW coil for cleanliness (clean if dirty)	Annual															
		Check collar connections of any flex ducts for integrity	Annual															
Keeper's House	Heating Loop	Check cleanliness of finned tube	Annual															
Control System	Control Panels (4 total)	Verify programmable logic controller operation and perform diagnostics test	Annual															
		Verify power supplies are maintaining proper voltages	Annual															
		Check the calibration of the temperature & RH sensors	Annual															
		Replace any blown fuses (Verify spare fuses are in the control panel)	Annual															
		Tighten screw terminals in the control panel and check wiring integrity	Annual															
		Clean control panel of dirt and debris	Annual															
		Verify proper control of all field devices and automated equipment including valves, sensors, relays, etc.	Annual															